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National
Aeronautics and
Space
Administration

Applications Notice

(E83-10228) APPLICATIONS NOTICE FOR PARTICIPATION IN THE LANDSAT-D IMAGE DATA QUALITY ANALYSIS PROGRAM (NASA) 57 p
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FOR PARTICIPATION IN THE

LANDSAT-D IMAGE DATA QUALITY ANALYSIS PROGRAM

OCTOBER 23, 1981

NASA

National Aeronautics and
Space Administration

October 23, 1981

Dear Colleague:

This letter calls your attention to opportunities to take part in the Landsat-D Image Data Quality Analysis (LIDQA) program. The objectives of the LIDQA program are to quantify Landsat-D sensor and systems performance from a user applications point of view, and to identify any malfunctions that may impact data applications. Data obtained by the Landsat-D Thematic Mapper (TM) and Multispectral Scanner (MSS) sensor systems will be utilized in this program to quantitatively characterize and assess the performance of the TM, the MSS, and their attendant ground data processing systems relative to the specifications for these systems.

Five enclosures are provided in this package to assist you in preparing a research proposal for potential participation in the LIDQA program. Enclosure 1 provides greater detail on the nature and scope of the activities that are envisioned under this program. Enclosure 2 contains guidance that will be helpful in preparing proposals. Enclosure 3 provides an up-to-date description of the Landsat-D project, including discussions on data acquisition, ground data processing and performance goals, and specific areas of interest relative to image data quality. Enclosure 4 describes the Landsat-D Assessment System (LAS) facility at the Goddard Space Flight Center (GSFC), which will be available to approved investigators for use in analyzing Landsat-D TM and MSS data. Enclosure 5 is a reprint of a paper that discusses the anticipated performance of the TM.

Participation in the Landsat-D Image Data Quality Analysis program is open and unsolicited proposals may be submitted at any time. However, to ensure a coordinated effort of funded activities at the time of launch (in the third quarter of 1982), it is contemplated that an initial evaluation of research proposals will take place in January 1982. Proposals received after this evaluation period will be judged in light of available funds. Submission of proposals on a no-cost-to-NASA basis are encouraged, particularly in situations where the proposing organization (a) is intimately involved in the analysis or distribution of Landsat data products (e.g., certain Federal agencies) or (b) stands to gain financially from the detailed information and knowledge obtained by participation in this analysis activity.

Landsat-D Image Data Quality Analysis activities are expected to last from 1 to 3 years. It is anticipated that the characterization of the Landsat-D MSS data should be completed within the first 6 months after launch in order to verify that the MSS sensor is functioning properly and that the users will be satisfied with the data. Proposals concerning the characterization of TM data may be expected to stretch over a longer period of time due to the newness, complexity, and volume (high data rate) of data. It is anticipated that approximately 10 studies will be funded in support of all proposed activities.

Domestic proposals should be sent to NASA/Goddard Space Flight Center, Code 100.2 (Reference AN:GSFC-81-A), Greenbelt, MD 20771.

Foreign proposals will be evaluated on the same basis as U.S. proposals, but will be accepted only on a no-cost-to-U.S. basis. General questions concerning the establishment of such cooperative projects should be addressed to International Affairs Division, Code LID-18 (Reference GSFC-81-A), Washington, DC 20546, USA. Foreign proposals should be sent to this address also.

Sincerely,

A. Thomas Young
Director, Goddard Space Flight Center

Enclosures ([illegible])

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ENCLOSURE 1

Applications Notice for the Landsat-D Image
Data Quality Analysis Program

Background and Objectives

The Landsat series of satellites have provided exciting and useful views of the Earth since the first Landsat satellite was launched in July 1972. Although various instruments have been carried by the Landsat satellites, data acquired by the Multispectral Scanner Subsystem (MSS) have been the most widely used. Nine years of observations covering much of the Earth on a repetitive basis have been acquired by the MSS instruments on Landsats 1 through 3, and stored in the form of images and computer compatible tapes (CCT's). These observations form a valuable data base for Earth resources scientific studies and management efforts.

Since the early 1970's, efforts have been underway to provide an improved Earth-observing capability over that provided by the MSS. These efforts have been in the execution phase under the Landsat-D program since 1977. (See Enclosure 3.) The primary instrument on the Landsat-D spacecraft will be the Thematic Mapper (TM), which is a second generation earth-observing sensor. While the TM relies heavily on the technology of the first generation sensor, the MSS, it is designed to achieve finer spatial resolution, sharper spectral separation, improved geometric fidelity, and greater radiometric accuracy and resolution than its MSS predecessor. (See Enclosure 5.) Further, the TM will acquire data in seven spectral bands covering the visible, near infrared, middle infrared, and thermal infrared regions of the electromagnetic spectrum, in comparison to the MSS which has four bands covering the visible and near infrared regions. Both the TM and familiar MSS will be carried on Landsat-D, which is scheduled for launch in the third quarter of 1982.

As a result of these sensor system improvements, the remote sensing community can expect to have an improved capability to extract useful information from satellite-acquired data of the Earth's surface. However, significant challenges lie ahead in: (a) characterizing Landsat-D sensor and mission performance and (b) preprocessing, processing, and analyzing the order of magnitude increase in data volume associated with improved sensor resolution (i.e., 85 megabits/sec. transmitted from the TM versus 15 megabits/sec. from the MSS). Many of these challenges will be met through the implementation of the Landsat-D Image Data Quality Analysis (LIDQA) program by NASA at the Goddard Space Flight Center (GSFC). The primary objectives associated with the LIDQA program are to:

- Characterize Landsat-D sensor (TM and MSS) and mission performance from the standpoint of "Did we meet performance specifications?" in such areas as spectral, spatial, and

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radiometric resolution, geometric rectification, etc., and "How does the measured performance affect image data quality and utility?"

- Compare MSS data from Landsat-D to MSS data from previous Landsat missions to ensure continuity of standardized MSS data to the user community.

Emphasis on the engineering and systems performance analyses embodied within the first objective is expected to continue over a 1 to 3 year period, while it is desired that the second objective be accomplished within 6 months after launch (i.e., before the turnover of MSS data production to NOAA).

Comparison of the LIDQA Program to Previous Landsat User Investigation Programs

Previous Landsat missions have sponsored user investigation programs to ascertain the applicability of satellite-acquired data for Earth resources management. The LIDQA program differs somewhat from these earlier programs by placing emphasis on engineering and systems performance analyses. This emphasis will continue through 1984. The purpose of this emphasis is to define the characteristics and quality of the output data in terms useful to the user community. This approach is compatible with the anticipated complexity of the TM data and the small amount of TM data that will be available to the user community until operational ground processing begins in January 1985. (See Enclosure 3.)

Research Activity

Research activity in support of the LIDQA program is closely coupled to characterizing or quantifying the performance of the TM and MSS sensors and the Landsat-D Image Generation Facility (IGF) relative to providing quality data products. Rather stringent performance specifications have been established for the sensors and the IGF. The specifications for the IGF are discussed in Enclosure 3 and are summarized in Table 1.

The TM system requirements and specifications are summarized in Table 2. A discussion of anticipated TM performance relative to these specifications is provided in Enclosure 5.

Many of the TM and MSS performance requirements can be validated on the ground before launch, but others cannot be validated until after launch and then only through careful and detailed analysis of the imagery collected by the sensors. This AN calls attention to the continuing opportunity to participate in the LIDQA program by proposing new and innovative techniques to characterize sensor and mission performance, not simply from an engineering and systems performance point of view, but primarily from an applications/user

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Table 1
Landsat-D/D' Ground-Segment Image Performance Requirements

Function/Operation	Performance Objective
Turnaround	48 hours after receipt of raw sensor data at GSFC to generation of archival products (worst-case averaged over 10 days)
Radiometric error correction (relative interdetector)	±1 quantum level over full range
Geometric error correction (nominal conditions with ground control points (GCP's))	0.5 sensor pixel (90% of the time) (with sufficient correlatable GCP's)
Temporal registration error	0.3 sensor pixel (90% of the time) (with sufficient correlatable control points)
Map projections supported	Space oblique mercator Universal transverse mercator/polar stereographic
Resampling algorithms supported	Cubic convolution Nearest neighbor

point of view (i.e., quantify performance relative to the potential impact on data applications). Thus, it is anticipated that LIDQA proposed activities will emphasize the particular performance specification(s) that will be addressed and how it (they) will be addressed from an applications/user point of view. The intent of the LIDQA program is to quantify sensor and systems performance as manifested by image data quality, and suggest improvements, as appropriate, so that the highest quality data products can eventually be made available to the user community.

Proposers are encouraged to carefully read the discussions of "Ground Segment Image Performance and Production Requirements" and "TM and MSS Image Data Analysis Plans" that are presented in Enclosure 3 and TM performance that is presented in Enclosure 5. These discussions provide an appropriate background and highlight specific areas of concern relative to image data quality.

Table 2
TM System Specifications*

Spatial Coverage

IFOV size - bands 1 to 4	$\leq$43.2 μrad
- bands 5 and 6	$\leq$46.35 μrad
- band 7	$\leq$174.4 μrad
Response at 2 IFOV's	$\leq$1% max

Band-to-Band Registration (Alongtrack and Cross-track)

Bands 1 to 4	within 0.2 IFOV
Bands 1 to 4 to bands 5 & 6	within 0.3 IFOV
Bands 5 and 6	within 0.2 IFOV
Bands 5 and 6 to band 7	within 0.2 band 7 IFOV.

Square Wave Response (Along-track and Cross-track)

Bands 1 through 6

Ground Target Size (m)	500	60	45	30
Modulation Response	1	0.85	0.70	0.35

Band 7

Ground Target Size (m)	2000	240	180	120
Modulation Response	1	0.85	0.70	0.35

Radiometric Accuracy

Radiometric accuracy for each detector channel in each spectral band	$\leq$10% absolute (full scale radiance)
	$\leq$2% relative between bands 1-6
shall be measured to:	$\leq$1/4 RMS noise level of the detector channel (channel to channel)

Radiometric Sensitivity

Signal-to-noise ratio (SNR) at low flat radiance input

Band 1	$\geq$32
Band 2	$\geq$35
Band 3	$\geq$26
Band 4	$\geq$32
Band 5	$\geq$13
Band 6	$\geq$5
Band 7	$\leq$0.5°K NETD at 300°K extended scene

Coherent noise photos – no discernible pattern

Step Response

Overshoot/undershoot	$\leq$10.0% of the step size
Bands 1 through 6	±1.5% of final value within 30 μsec and ±1.0% within 60 μsec after start of response
Band 7	±1.5% of final value within 120 μsec and ±1.0% within 240 μsec after start of response

Rise Time

Bands 1 through 6	$\leq$ 20 μsec
Band 7	$\leq$80 μsec
Variation of response time between channels of each band	$\leq$0.5 μsec
Signal droop	$\leq$0.5% deviation after first 100 μsec

Scan Modulation

Peak-to peak signal variation across a scan line from a uniform radiance scene	$\leq$0.5% average signal

Full Scale Input

SNR at full scale input, linear mode

Band 1	$\geq$85
Band 2	$\geq$170
Band 3	$\geq$143
Band 4	$\geq$240
Band 5	$\geq$75
Band 6	$\geq$45
Band 7	$\leq$0.42°K NETD at 320°K

*Bands are numbered sequentially relative to their location within the electromagnetic spectrum (i.e., Band 7 is thermal IR, not middle IR)

Although not inclusive, the following "shopping list" broadly identifies examples of several potential "performance" areas for consideration. This shopping list is subdivided into three engineering/systems performance categories: TM performance, MSS performance, and ground data processing (i.e., IGF) performance.

a. TM Performance (Relative To Specifications and MSS Capability)

(1) Spatial and Geometric

- Effective spatial resolution
- MTF and frequency response
- Edge response and settling time
- Band to band registration
  - Mirror velocity profile

(2) Radiometric and Spectral

- Signal to noise/noise equivalent radiance
- Dynamic range
- Calibration
  - Absolute
  - Relative
    - Band to band
    - Channel to channel within a band

b. MSS Performance (Relative To Specifications and Past MSS Performance)

(1) Same as for items listed under TM performance

(2) Comparison with previous MSS instruments

- Wider scan angle
- Slightly different spatial resolution at 705 km flight altitude
- Spectral and radiometric differences

c. Ground Data Processing Systems Performance (MIPS*, TIPS**, Relative To Specifications)

(1) Radiometric

- Calibration/destriping techniques
- Quantization effects
- Replacement approaches for bad detectors
- System noise correction procedures

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* MIPS = MSS Image Processing Subsystem
** TIPS = TM Image Processing Subsystem
See Enclosure 3 for details.

(2) Geometric

- Jitter effects
- Bowtie and varying altitude effects
  - Scan gap and overlap
- Registration procedures
  - Geodetic/scenes to map
    - Identification of ground control points
    - Accuracy of ground control points
  - Scene to scene accuracy
  - Use of Global Positioning System (GPS) data
  - Effects of various resampling procedures

<u>Proposal Preparation</u>

Proposals should be prepared and submitted as described in Enclosure 2. In addition to proposals by individual investigators, "team proposals" may be accepted when the nature of the contemplated research makes such an approach logical and effective.

<u>Additional Information</u>

Proposers are reminded that the Landsat-D Assessment System (LAS) facility at GSFC will be available to approved investigators for use in analyzing Landsat-D TM and MSS data. The LAS computer system is a state-of-the-art minicomputer that is interfaced to a high-speed array processor. Three sophisticated image analysis terminals will be available for interactive display and analysis of data. The LAS facility is discussed in greater detail in Enclosure 4.

Also, proposers should be aware of the limited capability in the United States to acquire TM data during the first few months following the Landsat-D launch. A Transportable Ground Station (TGS) located at GSFC will allow TM data acquisition over the eastern United States out to approximately the 100° meridian. The reason for this initial limitation in TM data acquisition capability is discussed in Enclosure 3 and the TGS acquisition circle is illustrated in Figure 2 of Enclosure 3. This geographic limitation should be taken into account if proposers are considering unique ground targets (e.g., field patterns), not within the TGS acquisition circle, for characterizing sensor performance. Note that ground-data processing of TM data is limited to approximately one scene per day during the first year following launch. (See Enclosure 3.)

<u>Future Information</u>

Any questions relating to this Applications Notice should be addressed to Mr. Darrel L. Williams, Assistant Landsat-D Project Scientist, NASA/Goddard Space Flight Center, Code 923, Greenbelt, Maryland, 20771 or telephone (301) 344-8860, 344-7282, or 344-6481.

ENCLOSURE 2

Guidelines for Preparing Proposals

Purpose

These guidelines contain suggested content and format information and procedures for submission of unsolicited proposals for research related to NASA's Landsat-D Image Data Quality Analysis program. They are consistent with NASA's UAO Brochure, July 1980, The NASA University Program: A Guide to Policies and Procedures (available from University Affairs Office, Code LU-16, NASA Headquarters, Washington, DC 20546).

General Guidelines

a. NASA Policy on Evaluation of Unsolicited Proposals

Proposers should be aware of NASA's general policy concerning evaluation of unsolicited proposals. Specifically, the NASA Procurement Regulation (NHB 5100.2B), Part 4, subpart a - unsolicited proposals, specifies that the initial receiving (coordinating) office, before making a comprehensive evaluation of a document apparently submitted as an unsolicited proposal, shall determine that the document:

(1) Contains sufficient technical and cost information to enable meaningful evaluation

(2) Has been approved by a responsible official or authorized representative of the organization submitting the proposal, or a person authorized to contractually obligate the organization

If the document does not meet these requirements, the offeror will be given the opportunity to provide the required data.

When an unsolicited proposal meets the above criteria, it is then circulated for comprehensive evaluation. Again, the NASA Procurement Regulation specifies that the comprehensive evaluation shall consider, in addition to any other criteria, the following:

(1) Unique, innovative, or meritorious methods, approaches, or ideas, which have originated with or assembled together by the offeror that are contained in the proposed effort or activity

(2) Overall scientific, technical, or socio-economic merits of the proposed effort or activity

(3) Potential contribution which the proposed effort is expected to make to the agency's specific mission if pursued at this time

(4) Capabilities, related experience, facilities or techniques, or unique combinations thereof, which the offeror possesses and offers and which are considered to be integral factors for achieving the scientific, technical, or socio-economic objective(s) of the proposal

(5) Qualifications, capabilities, and experience of the proposed principal investigator, team leader, or key personnel who are considered to be critical in achieving the objectives of the proposal

It is important to the NASA and the total Landsat-D Project effort that each of the received proposals be given peer evaluation so that the resulting investigations program will be fully responsive to the needs of the total Landsat-D Program and the applications community. The peer evaluation group may consist of government (both NASA and nonNASA) and nongovernment personnel and the evaluation activity will be managed and executed by the Landsat-D Project Science team. Final approval of the selection of proposals will be provided by the Associate Administrator, for the Office of Space and Terrestrial Applications at NASA Headquarters.

b. Technical Data

It is NASA's policy to use the technical data contained in proposals for evaluation purposes only. Where any of such technical data constitutes a trade secret under the law and the offeror, or his proposed subcontractor, desires to maintain trade secret rights in such technical data the following "Notice" must be affixed to the cover sheet of the proposal specifying therein the pages of the proposal that contain trade secrets to be restricted in accordance with conditions of the "Notice." Thereafter, it is NASA policy to protect such noticed technical data as a trade secret. NASA assumes no liability for use or disclosure of any technical data to which the "Notice" has not been applied.

NOTICE

Data on pages ___________ of this proposal constitute a trade secret. It is furnished to the Government in confidence with the understanding that it will not, without permission of the offeror, be used or disclosed other than for evaluation purposes; provided, however, in the event a contract is awarded on this proposal, the Government may obtain in the contract additional rights to use and disclose these data.

Proposal Content and Format

The content of the proposal should be in sufficient detail so as to enable a reviewer to make a judgment with respect to:

- The relevance of the proposed research to the objectives of the Landsat-D Image Data Quality Analysis program as presented and discussed in Enclosure 1
- The probability that the investigator(s) will be able to accomplish the stated objectives within the requested resources
- The proposal's overall value, compared to other proposals that participate within the same area of research in the program

When the work to be performed consists of two or more separate and distinct tasks, the resources requested for the accomplishment of the separate tasks should be provided.

Proposals should be limited to no more than 12 single-spaced, typewritten pages (any other pertinent information such as publications, design data, etc., may be included as enclosures) and contain at least the following material assembled in the order given:

a. Cover Letter--Each proposal should be prefaced by a cover letter signed by an official of the investigator's organization who is authorized to commit the organization to the proposal and its content. Their cover letter should refer to one of the general research areas called out in Enclosure 1.

b. Title Page--The title page should contain the following:

   (1) A short descriptive title of the proposed investigation

   (2) The name of the proposing organization(s)

   (3) The names, full addresses, telephone numbers, and affiliations of the principal investigator and all coinvestigators

   (4) The date of submission

   (5) A brief statement regarding special needs or facilities, indicating what is needed, and the appropriate time scale

c. Abstract

   The abstract should include the following:

   (1) A brief statement of the overall objective and justification of the work

(2) A brief listing of the work to be accomplished and the approach to be used during the award period

(3) A bibliography of one or two recent publications, by the proposer, of work relevant to the proposal.

d. Description of Proposed Research--The description should contain a brief introduction, background, and justification that includes a full statement of the research proposed, identifying and relating the key elements. Address the nature and amount of experimental data involved; describe the methods or approaches to be used; and discuss the advantages of the proposed approach over alternatives.

When it is expected that the research will require more than 1 year for completion, the proposal should cover the complete project to the extent that it can be reasonably anticipated. Principal emphasis should be on the first year of work. The description and cost plan should each distinguish clearly between the first year's work and that planned for subsequent years. NASA reserves the right to fund incrementally any contract/grant resulting from unsolicited proposals that are received. In no case should the proposal extend beyond 3 years duration.

e. Data Requirements--Each investigator is responsible for identifying: (a) the need for TM and/or MSS data to be collected over a specific geographic location(s), (b) the number of acquisitions needed and when (i.e., time of year, day or night, etc.), (c) the type and number of data products needed, and (d) the availability of existing data for comparisons of Landsat-D MSS to previous MSS data. The investigator should also plan for purchasing these data from appropriate repositories such as the EROS Data Center.

f. Support Facilities--Laboratories, specialized equipment, etc., that are available for use in the Landsat-D research should be described. Equipment proposed to be purchased with NASA funds should be specified and the expenditure justified. Those investigators who plan to use the Landsat-D Assessment System facilities at GSFC should identify their desire to do so, and estimate the amount of usage required to obtain the goals stated in their proposal.

g. Scientific and Technical Personnel--A brief summary of the scientific background and relevant experience of the Principal Investigator (PI) and of each Coinvestigator (Co-I), should be given.

(1) PI--An investigator who has primary responsibility for the accomplishment of the proposal objectives should be identified. Usually, NASA will approve only a single individual as "PI."

(2) Co-I--This title should be restricted to a limited number of well qualified, senior-level scientists, who will be contributing material to the research and who would be capable of independently directing the proposed research.

(3) Scientific Collaborators--All qualified scientists, whose work on the research will be sponsored by NASA funds, should be listed.

h. Investigators at Other Institutions--In those cases in which research is to be conducted by scientific collaborators who are not employed by the proposing institution, but are to be funded through this award, the nature of the anticipated contractual arrangements between the proposing institution and these investigators should be specified.

i. Sources of Outside Support--The proposal should list other supported research conducted by the PI, name of sponsor, and title of the research. There should be a similar listing (of NASA support only) for each Co-I who is to contribute to the research.

j. Dates--The proposal should include the date of submission and the proposed starting and completion dates of the research.

k. Foreign Proposals--Foreign proposers are responsible for arranging their own funding for the proposed investigation; therefore, cost information is not applicable to foreign proposals. Investigators should be careful to comply with all other guidelines.

l. Cost Plan (U.S. proposals only--including all federal establishments)--Proposers should be aware that cost sharing by nonfederal organizations is statutorily required in any contract for basic or applied research that results from an unsolicited proposal, unless the proposer certifies in writing, that it has no commercial, production, educational, or service activities on which to use the results of the research and that it has no means of recovering any cost sharing on such projects.

Proposals may be prepared according to the guidelines of the institution submitting the proposal and should include:

1. Salaries and wages ________

2. Materials, supplies, and miscellaneous ________

3. Laboratory costs (including use or rental of equipment and special services) ________

4. Travel (domestic and foreign) ________

5. Equipment ________

6. Computer time ________

7. Publication and communications costs ________

8. Cost of data ________

9. Other direct costs ________

10. Overhead ________

11. Total operating budget for Grant or Contract Period (generally 12 months) ________

12. Estimated total operating budget through completion of research ________

13. Institutional contribution ________

14. Total months for completion of research ________

Procedures for Submission

a. Domestic Proposals

Twelve copies of the proposal are desirable. All domestic proposals should be mailed directly to the following address:

NASA/Goddard Space Flight Center
Code 100.2 (Reference AN:GSFC 81-A)
Greenbelt, Maryland 20771

One copy of the proposal should bear the original signatures of the PI and an authorized official of the proposer's sponsoring organization.

b. Foreign proposals

Responses for participation by individuals outside the United States of America should be typewritten in English. These responses should be reviewed and endorsed, in English, by an appropriate sponsoring government agency in the proposer's country. Twelve copies, one of which bears the original signature of the endorsed responses, should be forwarded to the following address:

National Aeronautics and Space Administration
International Affairs Division
Code LID-18 (Reference GSFC-81-A)
Washington, DC 20546
U.S.A.

Include a reference to the number of this Applications Notice. Foreign responses received by the International Affairs Division will go through the same evaluation process as U.S.-affiliated responses. Should a foreign respondent be accepted, NASA will arrange with the sponsoring foreign agency for the proposed participation on a cooperative basis, in which NASA and the sponsoring agency will each bear the cost of discharging its respective responsibilities.

ENCLOSURE 3

DESCRIPTION OF THE LANDSAT-D MISSION

Background

Since the early 1970's launch of the Landsat series of satellites, a considerable amount of research has been directed towards extracting useful information from satellite remotely sensed data for monitoring the Earth's resources. The use of the observations from space, provided by the Multispectral Scanner (MSS) Subsystem on Landsats-1, -2, and -3 has been fairly well determined, but the data have been found lacking in certain respects. Three characteristics of Landsat MSS data often identified as limiting factors are spatial resolution, spectral resolution, and timely availability of data. The need for improved sensor capabilities over those of the MSS was envisioned before the launch of Landsat-1, and the characteristics of a new sensor system have been under study since 1970. The new, experimental Earth resources monitoring system that has evolved through a series of study efforts and with the guidance of several advisory groups representing all facets of the remote-sensing community is called Landsat-D. The Landsat-D system is presently scheduled for launch in the third quarter of 1982 and is designed to be a complete, highly automated data gathering and processing system that should contribute substantially to more effective remote sensing of Earth resources. The principal instrument on the Landsat-D spacecraft will be the Thematic Mapper (TM), that is designed to provide spatial, spectral, and radiometric capabilities significantly more advanced than those of the MSS. A four-band MSS similar to that flown on Landsats 1 and 2 will also be carried on Landsat-D and will collect data simultaneously with the TM.

The five major objectives of the Landsat-D project are to:

- Assess the capability of the TM and associated systems to provide improved information for Earth resources management
- Provide, for both domestic and foreign users, a transition from MSS data to the higher resolution and data rate of the TM
- Provide for system level feasibility demonstrations together with NOAA and other user agencies to define the characteristics of an operational system including transfer of Landsat D/D' management from NASA to NOAA
- Provide for continued availability of MSS data
- Permit continued foreign data reception

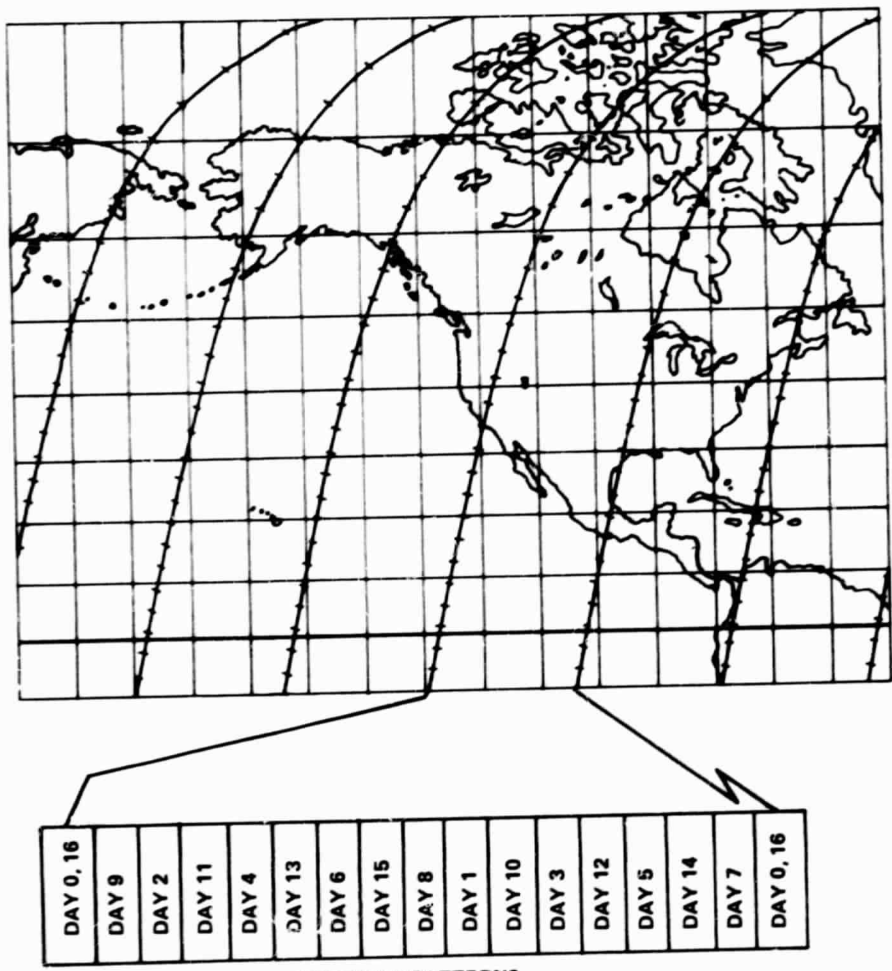
The Landsat-D mission consists of a flight segment that is an orbiting observatory and a ground segment that includes the necessary data processing and support systems. The satellite will be launched from the Western Test Range (WTR) near Vandenberg Air Force Base in California. The launch vehicle will be an upgraded Delta rocket designated Delta 3920. The spacecraft will be launched into a near-polar orbit having a 98.22-degree inclination to the equatorial plane. The nominal altitude will be 705 kilometers. In this orbit, Sun-synchronism will be achieved with a 9:45 a.m. equatorial crossing time (±15 minutes) for the descending (north to south) daylight pass of the satellite orbit. The repeat period will be 16 days. Figure 1 provides a summary of the coverage pattern and characteristics of the 16-day repeat cycle.

Flight Segment

The spacecraft component of the flight segment will be the Multimission Modular Spacecraft (MMS). This spacecraft will perform the basic functions of providing power, altitude and attitude control, and the command and data-handling systems. The MMS has improved attitude-control capability over previous Landsat systems. The pointing accuracy is specified to be 0.01 degrees (1-sigma value), and the stability is 10^{-6} degrees/second (1-sigma value). To appreciate the advantages afforded by the MMS in this area, one can compare these performance values to the 0.7-degree pointing accuracy and 0.01-degree/second stability values associated with Landsats-1 through -3. In addition, the attitude control system information provided by the MMS will be supplemented by an angular displacement sensor (ADS) mounted on the TM. The ADS will provide more precise information that is needed to account for the effects of vibration (jitter) on imagery data. This anticipated vibration could be caused by the scan-mirror oscillations of the MSS and TM sensors and vibrations induced by stepper motor drives on the large Tracking and Data Relay Satellite (TDRS) system antenna and solar-array mechanisms.

Data Acquisition

One of the major advances in the Landsat-D system is the use of a series of communication satellites to gather all data in near-real time. The two communication satellite systems involved are the TDRS system and the Domestic Communications Satellite (DOMSAT) system. The use of the TDRS system will eliminate the need to rely upon on-board tape recorders, which is certainly a positive step forward in concept, because tape recorders have historically failed on previous Landsat missions. The DOMSAT system will be used to greatly reduce time delays previously encountered in shipping sensor data from the Landsat ground receiving stations to the data processing facility at the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, and subsequently to data distribution centers such as the EROS Data Center in Sioux Falls, South Dakota.



ALTITUDE: 705.3 KM
INCLINATION: 98.2 DEG
REPEAT PERIOD: 16 DAYS
ORBITS/REPEAT PERIOD: 233
ORBITS/DAY: 14 9/16
TRACE SPACING: 172 KM

The distance along the abscissa of the diagram below is essentially the distance between successive orbits on a given day. The intent of this diagram is to show how this distance is covered over the repeat period. The cross-hatched boxes show swath location in space and time for Landsat-D.

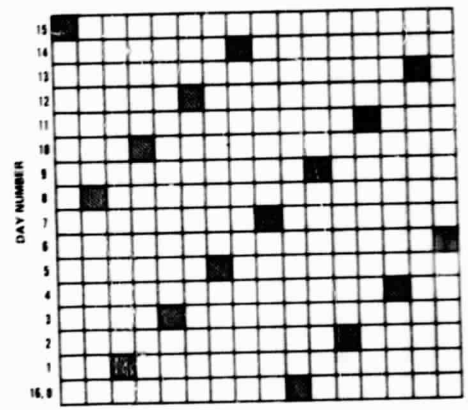


Figure 1. Landsat-D Orbit Characteristics

The TDRS antenna located on the Landsat-D spacecraft will permit command signals, telemetry signals, and TM and MSS sensor observations to be relayed through one of the two satellites, in the TDRS system, to a single ground receiving station at White Sands, New Mexico. The TDRS satellites will be placed in geosynchronous orbits at 41°W and 171°W longitudes, respectively. This configuration will permit the acquisition of TM and MSS sensor data of nearly all of the Earth's surface. A small area of land lying approximately between 67°E and 82°E longitudes and between 50°N and 50°S latitudes will be excluded from coverage by the geometry of the system. (See the following notice.)

To handle the high-data rates associated with Landsat-D and other space missions, the TDRS system uses a Ku-band (≈15 GHz) frequency for communications. The Ku-band frequency will support simultaneous transmission of both TM and MSS data. Because this frequency is somewhat more affected by atmospheric conditions than previously applied communications links, a relatively cloud-free location (White Sands, New Mexico) was chosen as the point for receiving TDRS information. Sensor data received at the White Sands facility will be demodulated, separated, and recorded on separate wide-band digital data recorders. Once each 8-hour shift, compacted raw data tapes will be replayed from White Sands to the GSFC processing facility by the DOMSAT system. The 50 megabits per second DOMSAT capabilities will support the serial transfer of TM data at one-half real time and MSS at two times real time. Under normal circumstances this data off-loading scheme will ensure a data delay of no more than 8 hours from sensor observation to availability for processing at the GSFC facility. In the event of a DOMSAT support failure lasting longer than 2 days, data tapes will be mailed directly to GSFC to prevent unmanageable backlogs.

Landsat-D will also be able to directly communicate with and send data to Landsat ground receiving stations. For this purpose, X-band (8.025 to 8.4 GHz) and S-band (2206 to 2300 MHz) frequencies will be used. Although S-band has been used for previous Landsat missions, the high-frequency X-band link is required for handling the TM data streams. As a result, stations that intend to receive TM data must

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NOTICE: Note that delays until December 1962 (41°W) and June 1983 (171°W), in the deployment of the TDRS system, will significantly limit the amount of TM data that can be captured at the beginning of the Landsat-D mission. A Transportable Ground Stateion (TGS) located at GSFC will allow TM data acquisition over the eastern United States at the time of launch out to approximately the 100° meridian (Figure 2). TM data acquisition capabilities for the remainder of the United States will be provided following the deployment of the first TDRS satellite. MSS data will be captured through the Landsat Ground Station Tracking and Data Network (GSTDN) and selected foreign receiving stations until the TDRS system is fully operational.

Figure 2. Approximate TGS Land Mass Coverage

add X-band capabilities that were not previously required. Landsat-D MSS data will still be transmitted using the S-band.

Sensor Payload

The Landsat-D instrument payload consists of the TM and a four-band MSS similar to that flown on Landsat 1 and Landsat 2. The TM provides seven narrow spectral bands that cover four major regions of the optical portion of the electromagnetic spectrum. The regions and TM bandwidths are: visible (0.45 - 0.52 μm, 0.52 - 0.60 μm, 0.63 - 0.69 μm); near infrared (0.76 - 0.90 μm); middle infrared (1.55 - 1.75 μm, 2.08 - 2.35 μm); and thermal infrared (10.4 - 12.5 μm). The resolution field of view (RFOV) of the visible, near- and middle-infrared bands will be 30 meters, while the thermal-infrared RFOV will be 120 meters. The radiometric sensitivity of the TM will be improved over that of the MSS, even though the TM spectral bandwidths are more narrow and the ground sample size (i.e., RFOV) smaller. In conjunction with this improvement in radiometric sensitivity, the number of quantization levels has been increased from 64 to 256. A comparison of general Landsat-D TM and MSS sensor characteristics is provided in Table 3.

Table 3
Comparison of Landsat-D TM and MSS Sensor Characteristics

	Thematic Mapper (TM)		Multispectral Scanner Subsystem (MSS)	
	Micrometers	Radiometric Sensitivity (NEΔP)	Micrometers	Radiometric Sensitivity (NEΔP)
Spectral band 1	0.45 - 0.52	0.8%	0.5 - 0.6	0.57%
Spectral band 2	0.52 - 0.60	0.5%	0.6 - 0.7	0.57%
Spectral band 3	0.63 - 0.69	0.5%	0.7 - 0.8	0.65%
Spectral band 4	0.76 - 0.90	0.5%	0.8 - 1.1	0.70%
Spectral band 5	1.55 - 1.75	1.0%		
Spectral band 6	2.08 - 2.35	2.4%		
Spectral band 7	10.40 - 12.50	0.5K (NEΔT)		
RFOV		30M (bands 1-6) 120M (band 7)	82M (bands 1-4)	
Data rate		85 MB/S	15 MB/S	
Quantization levels		256	64	

In terms of basic design, there are at least two fundamental differences between the two instruments. First, the MSS scans and obtains data in one direction only and the TM scans and obtains data in both directions. The bidirectional approach was employed to reduce the scan rate and provide the dwell time needed to produce improved radiometric accuracy. Second, the TM detector arrays are located within the primary focal plane of the instrument, thus allowing incoming light to be reflected directly onto the detectors without transmission through fiber optics, as with the MSS. This configuration minimizes any loss in the intensity of incoming radiation. However, this approach requires that the detector arrays for the various spectral bandwidths be spaced apart in the focal plane by the equivalent of several raster lines, so the same point on the ground is not simultaneously scanned in all seven bands. Thus, accurate TM band-to-band registration depends upon precise time-registration and scan mirror profile repeatability. The anticipated performance of the TM is discussed in detail in Enclosure 5 of this package.

Ground Segment

The Landsat-D ground segment consists of a Control and Simulation Facility, a Mission Management Facility, an Image Generation Facility, a Landsat Assessment System, and a Transportable Ground Station. The Landsat-D ground segment is shown in Figure 3 and Figure 4.

In the replanning and rebaselining effort that took place within the Landsat-D project during 1980, most of the design changes occurred within the ground segment. In general, the processing capabilities for the MSS and TM data were separated as much as possible. By doing this, the important consideration of continuing and maintaining the flow of MSS data to the user community would not be affected by the data processing research and development efforts associated with the TM data.

The functions of the various components of the ground segment, listed above, can be briefly stated as follows:

a. Control and Simulation Facility (CSF)--The CSF will be a dedicated control center with the capability to operate two Landsat-D flight segments. The CSF will perform the following:

- Coordinate the scheduling of ground resources for acquisition of image data, communicate with the flight segment, and control and maintain the flight segment
- Provide off-line mission planning and analysis
- Control, monitor, and analyze flight segment performance

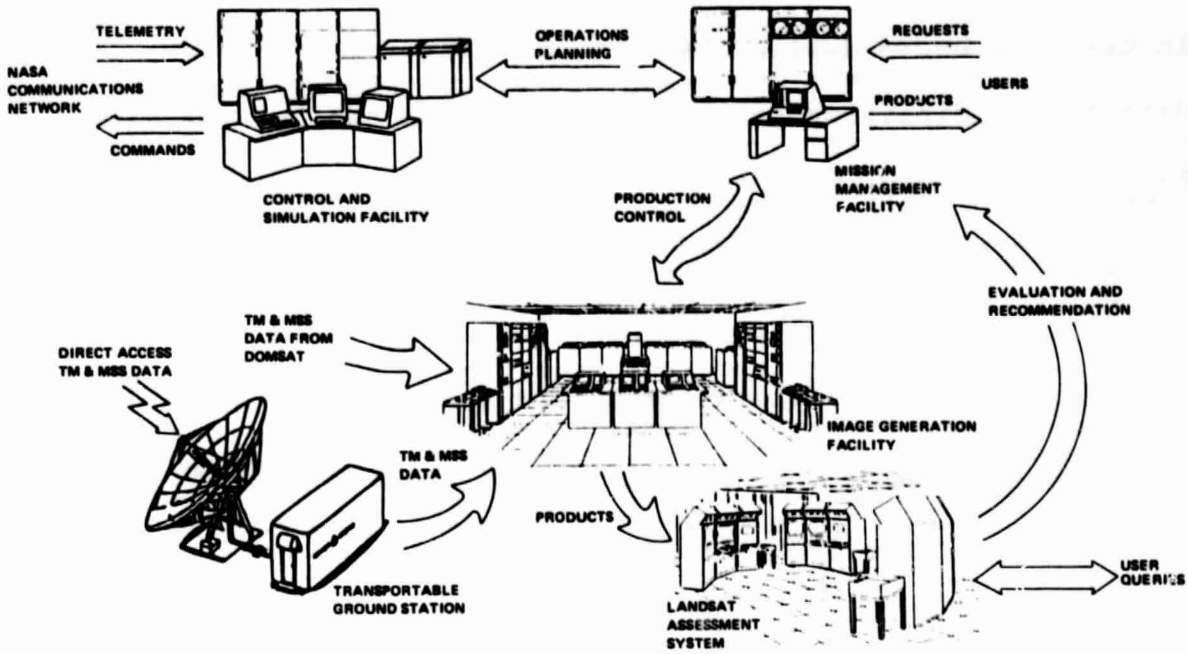

Figure 3. Landsat-D Ground Segment Configuration

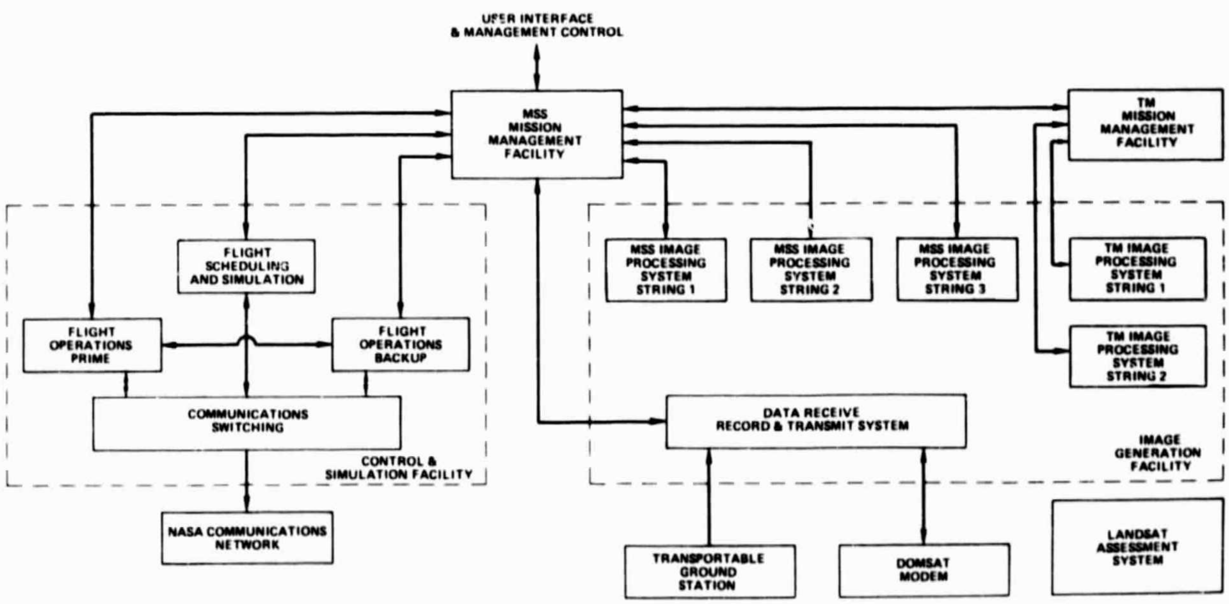

Figure 4. Landsat-D Ground Segment

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- Coordinate and direct TM and MSS operations for the acquisition of image data and delivery of the image data to the Image Generation Facility

b. Mission Management Facility (MMF)--The MMF consists of hardware, software, operations, and procedures to provide user request processing, image data production management, management reporting, data base management, control point library generation, inventory control, and ground segment management. The MMF is subdivided into two elements, MMF-MSS and MMF-TM, to maintain MSS and TM separability. Each element interfaces with the other to allow for the exchange of TM acquisition data.

c. Image Generation Facility (IGF)--The IGF is responsible for receiving and processing the raw instrument data to produce film and digital products to the requisite performance requirements, for both MSS and TM data.

Characterization of the performance of the MSS and the TM will be accomplished before transfer of management of each system from NASA to NOAA. Absolute geodetic accuracy and temporal registration requirements will be met to the extent that sufficient ground control points are available in the specific scene.

The IGF will consist of a Data Receive, Record, and Transmit Subsystem (DRRTS), a MSS Image Processing Subsystem (MIPS), and a TM Image Processing Subsystem (TIPS). As stated previously, there are distinct image processing subsystems for MSS and TM to provide complete separability of MSS and TM processing. Close inspection of the IGF layout, which is enclosed within the dashed lines in the right half of Figure 4, reveals the separation of the MSS and TM data processing strings. The MIPS uses three redundant strings of components composed principally of PDP VAX-11/780 and Floating Point Systems AP-180V data processors. The TIPS consists of two redundant strings of equipment that rely on VAX-11/780 hardware and a pipeline processor called the Federation of Functional Processors (FFP) developed by the General Electric Company.

The MSS element of the IGF will be used operationally. The TM element of the IGF will be used, initially, in an adaptive R&D mode and will subsequently evolve into an operational system after the TM sensor and its performance are characterized.

d. Landsat-D Assessment System (LAS)--The LAS facility within the ground segment was designed with an advanced data processing capability to facilitate the analysis of the higher

data rate associated with TM image data. The LAS has two principal functions that provide the following:

(1) Conduct detailed assessments of Landsat-D image data to demonstrate by analysis and test that the key mission objectives of providing improved information for Earth resources management and transition to the higher resolution and data rate of TM data are being met.

(2) Conduct a preliminary TM R&D early access program using the LAS facility for two purposes. The first is preparation of 1 TM scene/day to 241mm film, high density tape, and computer compatible tape using a priori geometric correction procedures. The second is measurement of on-orbit spacecraft disturbance effects (jitter), and evaluation and rectification, as possible, of the a priori ground segment (TIPS) procedures for geometric correction in the presence of jitter. The results of such analyses and the development of alternative procedures are expected to contribute to the subsequent phase of the TM R&D program through influence on TIPS processing. The duration of this program will be from D launch to D+12 months.

A more complete LAS facility description can be found in Enclosure 4 of this package.

e. Transportable Ground Station (TGS)--A TGS will be installed at GSFC for checkout of the Landsat-D local user transmission system. During the initial activation of the onboard instruments, this station will monitor the initial turnons in real time and will subsequently monitor the X- and S-band systems performance.

The TGS will transfer acquired TM and MSS data to the IGF in real time. Before TDRSS availability the TGS will be the only NASA receiving station for all TM data and eastern United States MSS data. (See the Notice on page 3-4.)

Ground Segment Image Performance and Production Requirements

The IGF within the ground segment is responsible for receiving and processing the raw instrument data from both the MSS and TM sensors to produce film and digital products. The intensity and concern for generating quality data products is reflected by the rather stringent and challenging performance and production requirements on the IGF, that are summarized in Table 4 and Table 5.

Table 4
Landsat-D/D' Ground-Segment Image Performance Requirements

Function/Operation	Performance Objective
Turnaround	48 hours after receipt of raw sensor data at GSFC to generation of archival products (worst-case averaged over 10 days)
Radiometric error correction (relative interdetector)	±1 quantum level over full range
Geometric error correction (nominal conditions with ground control points (GCP's))	0.5 sensor pixel (90% of the time) (with sufficient correlatable GCP's)
Temporal registration error	0.3 sensor pixel (90% of the time) (with sufficient correlatable control points)
Map projections supported	Space oblique mercator Universal transverse mercator/polar stereographic
Resampling algorithms supported	Cubic convolution Nearest neighbor

As a result, the schedule projections for the operational output of MSS and TM data are relatively conservative and the "when available" column in Table 5 should be noted.

Basically, full production and operational output of MSS data are expected within 6 months after launch or approximately January 1983.

Operational output of TM data is not expected until January 1985. The longer lead time associated with the operational output of TM data is influenced primarily by two factors: (a) The TIPS within the IGF will not be fully operational until approximately 1 year after launch, (b) algorithms to account for the anticipated "jitter" effects on TM band-to-band registration and geometric correction cannot be finalized until the satellite is launched and the magnitude of the high frequency vibrations are quantified.

In the case of the 48-hour turnaround objective, the ground segment was redesigned to incorporate a high level of backup alternatives using proven data-processing equipment when possible. The new configurations for the image generation procedures allow margin for reprocessing a substantial segment of the production requirements

Table 5
Summary of Ground System Products for Landsat-D

Instrument	Product	Quantity* Scenes/Day	When Available
MSS	MSS A Tape (HDT) (User Product) MSS 70mm film (Q.C. Product) (One Band Q.C. Product)	200	A. For first 3 months operating 2 lines, 2 shifts will produce 125 scenes B. After first 3 months operating 3 lines, 2 shifts will produce 200 scenes C. Turn over operational system to NOAA, 200 scenes/day at Landsat-D launch plus 6 months
	MSS CCT (A or P) (Q.C. Product)	2	A. At launch of Landsat-D
	MSS 241mm film (Q.C. Product)	4	A. At launch of Landsat-D (2 scenes/day) B. Launch plus 90 days (4 scenes/day)
TM	Thematic Mapper	1	A. Provide developmental TM processing using selected a priori jitter algorithms for one scene/day at the launch of Landsat-D. Film, A and P tapes and CCT's will be provided.
	TM A Tape (HDT) (User Product) 70mm film (Q.C. Product)	12 to 100	A. During the TM R&D period (which starts one year after the launch of Landsat-D), capability of processing 12 scenes/day with a priori knowledge of Flight Segment disturbances (jitter) B. One year after start of TM R&D period, 12 scenes/day shall be demonstrated operationally using a posteriori knowledge of jitter C. Six months later the system capability will be increased to 100 scenes/day and use a posteriori knowledge (in orbit measurements) of jitter. The system will be turned over to NOAA at this time.
	TM P Tape (HDT) (User Product) 241mm film (Q.C. and User Product	12 to 50	A. During the TM R&D period (which start one year after the launch of D) capability of processing 12 scenes/day with a priori knowledge of flight segment disturbances (jitter). B. One year after start of TM R&D period 12 scenes/day shall be demonstrated operationally using a posteriori knowledge of jitter. C. Six months later the system capabilitites will be increased to 50 scenes/day and use a posteriori knowledge (in orbit measurements) of jitter. The system will be turned over to NOAA at this time.
	TM CCT (A or P) (User Product)	2 to 10	A. By April 1984 2 scenes/day will be demonstrated B. Turn over operational system to NOAA, 10 scenes/day in January 1985

*A scene/day is defined as a Ground System output with a 48-hour turn around averaged over a 10-day period.

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each day to eliminate errors caught in quality checking. Several more points in the data-processing chain are to be available for performance checking and reporting than were available in Landsat 1 through Landsat 3 data-processing systems.

If data are lost because of suboptimum sensor performance (e.g., dead detectors), the present plan is to replace the poor data with the neighboring or last good data. For example, if a detector becomes inoperative and produces a scanline dropout, the present plan would be to repeat the data produced by the preceding scanline and clearly flag the data products that this has occurred. Alternatives, such as interpolating between neighboring scanlines or more sophisticated interpolation routines, are being studied and evaluated for increased representativeness and computation complexity. The current conclusion is that replacement of a lost scanline by the previous scanline is computationally simple and is therefore attractive for a large data-processing environment. Moreover, this approach is apparently almost as satisfactory as many other approaches in terms of its impact on data utility.

The radiometric correction procedures are of key interest to a majority of users of the TM and MSS data. It is expected that, for the MSS, the calibration wedge approach will be used to assess absolute and band-to-band fidelity during Landsat-D operation, and scene content histogramming will be used to monitor detector-to-detector gain and bias and to achieve the ±1 quantum level specification. On the TM, a series of three lamps will be operating at different intensities to provide eight levels of calibration intensity over the range of response for the instrument. The details for TM radiometric correction procedures are not yet available, but the MSS procedures are becoming more definitized. For detector-to-detector matching, means and variances for each sweep of the mirror will be compared to a moving mean of several sweeps to determine if the ±1 quantum level differences between channels is being met. This procedure is now being examined, using Landsat-3 data to see if it performs adequately over a useful range of scene conditions.

The geometric correction specifications for the MSS and TM data are quite stringent, particularly for the TM. The improved attitude control capability of the Multimission Modular Spacecraft may expedite the processing of MSS data in particular. However, the installation of the angular displacement sensor on the TM reflects the concern for the so-called "jitter" effects that result from the interaction of the scan vibrations produced by the MSS and TM and the drive mechanisms of the TDRSS antenna and solar array. The information provided by this sensor will be used to account for high-frequency (up to ≈100 cycles/second) vibrations that may affect the band-to-band registration and other geometric specifications already noted.

Significant corrections must also be made to account for off-nadir ("bow-tie") effects and scan gap or overlaps in TM data that may

occur because of the normal variations in orbital altitude that occur as the spacecraft proceeds around the Earth.

Algorithms to account for the effects mentioned are now in development* and will be supplemented to attain the geodetic and temporal registration specifications by the use of ground-control points. The selection and use of ground-control points will be an exacting and challenging procedure because of the accuracies needed for the TM data.

TM and MSS Image Data Analysis Plans

Given the complexity of the processing that must be applied to the sensor data from Landsat-D, it is clear that a careful analysis program will be necessary to ascertain if the sensors and attendant data are meeting specifications and achieving the applications potential envisioned at the start of the Landsat-D program. Plans have been developed to initiate a modest but formal investigation program in the 1982 to 1984 timeframe that will principally be of an engineering assessment nature. These investigations will focus on assessing the performance of the TM, the MSS, and their attendant data-processing systems relative to the specifications for these systems. (See Enclosure 1.)

For the MSS, the focus is to be on those features of the MSS data that result from Landsat-D operating at a lower altitude than Landsat 1 through Landsat 3. These features include effects, if any, on the application of the data associated with the larger scan angle of the Landsat-D MSS (14.93° versus 11.52°) and the slightly larger ground resolution element size (82 versus 79 meters). In addition, the relative and absolute calibration of the Landsat-D MSS must be evaluated. Relative calibration between channels, bands, and previous MSSs on Landsat 1 through Landsat 3 will be emphasized.

Both the performance of the TM and MSS must be evaluated relative to specifications. Dynamic range, frequency and transient response, scanmirror velocity profile, scan length and repeatability, are among the many parameters to be evaluated. As previously noted, a key part of the examination will be the evaluation of vibration (jitter) effects on the performance of the TM and MSS instruments.

The ground systems must achieve band-to-band registration, geodetic (scene-to-map) registration, and temporal registration (scene-to-scene) specifications. In addition, channel-to-channel differences

* A. Prakash and E.P. Beyer, "Landsat-D Thematic Mapper Image Resampling for Scan Geometry Correction," 1981 Machine Processing of Remotely Sensed Data Symposium, LARS, Purdue University, 1981, 11 pp.

within bands must be restrained to ±1 quantum level as far as possible. The data must be resampled, particularly for the TM, to meet registration specifications, and to account for off-nadir changes in picture element (pixel) size and shape and gaps or overlap between TM scans resulting from varying altitude (≈30 to 40 kilometers) over the course of an orbit or several orbits. Therefore, the effectiveness of these procedures must be evaluated. These aspects, as well as many others, will call for careful investigations.

Besides the engineering assessment activities alluded to previously, some limited observational science-type investigations are envisioned to obtain results that quantitatively typify the attributes of the TM relative to the MSS for Earth-resources management. However, it is planned that these efforts will programmatically remain secondary to the engineering assessment activities, noted previously, until 1984 or 1985. At that time applications that are research related to the TM should begin to reach significant magnitude commensurate with the achievement of full Landsat-D data processing capabilities and the operation of these systems by the operational Earth-resources satellite agency, NOAA.

Summary

Several key changes in the Landsat-D project have taken place during the past year, primarily in relation to the ground segment and the availability of data to the user community. Thus, previous articles describing the various aspects of Landsat-D may contain out-of-date information and should be treated accordingly. Major changes, highlights, and interesting aspects of the current Landsat-D program are as follows:

- Landsat-D is to be launched by the third quarter of 1982.
- Landsat-D' launch readiness is to be achieved within 12 to 15 months after Landsat-D launch.
- Protoflight TM and MSS are to be flown on Landsat-D.
- TDRSS will be the Landsat-D/D' observatory to ground segment communications network (TDRSS network to be deployed in 1983).
- GSTDN will be used until TDRSS network becomes available.
- TM data acquisition will be limited to direct readout to the TGS at GSFC until the TDRSS network is deployed. (TGS will provide coverage of the eastern United States out o approximately 100° meridian. (See Figure 2.)
- Data are to be transmitted directly to foreign ground stations.

- Global Positioning System (GPS) will provide ephemeris data.
- Predictive-fit ephemeris is to be used until GPS becomes operational.
- Angular displacement sensor is to be flown on Landsat-D and D'.
- MSS data processing is to begin at Landsat-D launch plus 14 days.
- NASA is to conduct TM evaluation at the 1-scene/day level during the first year and TM R&D processing at the 12-scene/day level during the second year of Landsat-D mission life.
- TM R&D quality data are to be available on a limited basis beginning 1 year after Landsat-D launch.
- TM processing capability at the 12-scene high-density tape, 12-scene 241-mm film master, and 2-scene computer compatible tape (CCT) product level per day is to be proven by July 31, 1984.
- TM processing capability at the 50-scene high-density tape, 50-scene 241-mm film master, and 10-scene CCT product level per day is to be achieved by January 31, 1985.

Conclusion

The Landsat-D project has progressed from the initial stage of plans and designs to the stage where the major elements and systems that comprise the overall Landsat-D system now exist and are being integrated for eventual launch and operation of Landsat-D in the third quarter of 1982. The anticipation of receipt of actual data is being manifested in the preparation of plans for engineering assessment analyses of Landsat-D MSS and TM data and the analysis of simulated TM data obtained from ground-based and airborne instruments. However, to achieve this next step in advancing technology for Earth resources monitoring and management using space technology, much remains to be done both before and after the launch.

ENCLOSURE 4

LANDSAT-D ASSESSMENT SYSTEM (LAS) FACILITY DESCRIPTION

OVERVIEW

The LAS is an integral part of the total Landsat-D ground segment. The configuration and facility layout of the LAS were developed with the scientific user community's needs and objectives in the Landsat-D operations period as prime considerations. See Figure 5 for a block diagram of the LAS system hardware. The system includes a Digital Equipment Corporation (DEC) VAX 11/780 minicomputer with one megabyte (MB) of main memory, seven high-speed input/output (I/O) ports, a low-speed I/O port, a Floating Point System (FPS) AP-180V high-speed processor, three Hazeltine image analysis terminals (IAT's), two high density digital tape recorders (HDDR's), and a variety of other standard peripherals.

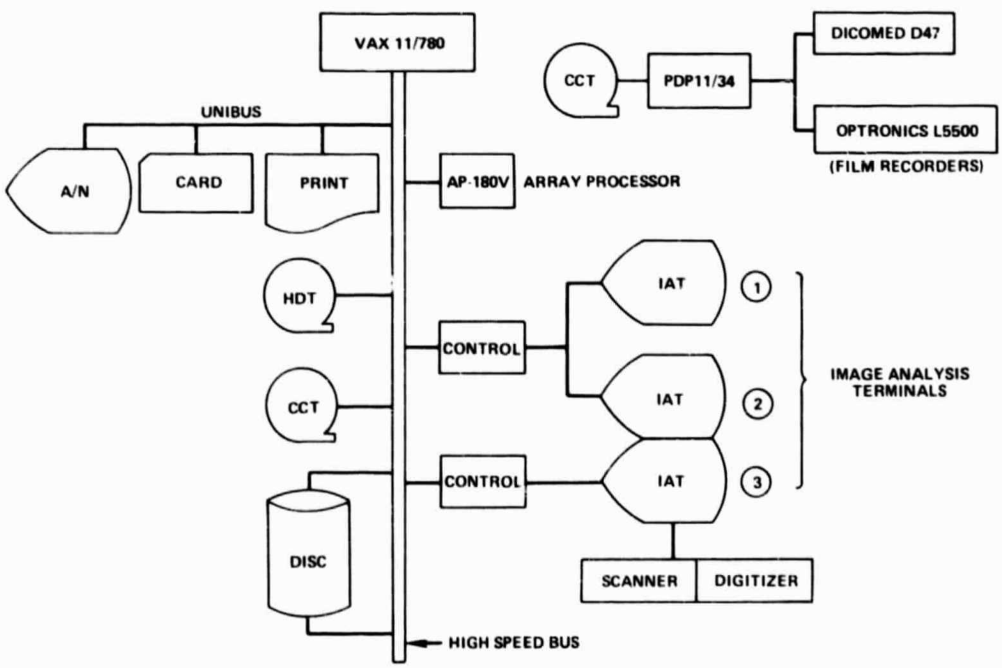

Figure 5. LAS Hardware Configuration

The LAS has been designed to handle a variety of I/O media (e.g., discs and tapes) and data formats. The LAS facility will be capable of accepting and producing computer compatible tapes (CCTs), high density digital tapes (HDDTs), and film images. Typical inputs to the system will include Thematic Mapper (TM) and Multispectral Scanner (MSS) data from CCT's and HDT's, as well as ancillary data from tape, film, maps, charts, and punched cards.

The LAS has been sized to process image segments varying from 512 lines by 512 picture elements per line, to full TM scenes of approximately 6500 lines by 6500 picture elements per line. Due to the volume of data associated with a full TM scene, LAS capabilities for extensive processing of full TM scenes are limited.

Use of the LAS facility by successful LIDQA proposers is optional, and access to the facility will be coordinated by the Landsat-D Project Scientist.

The following sections of this Enclosure will describe: (a) the system hardware and its configuration, (b) the systems and applications software that will be available at the time of launch, (c) the LAS user interface and system availability, and (d) the LAS physical plant.

SYSTEM HARDWARE AND CONFIGURATION

VAX 11/780

The VAX 11/780 is the host computer for the LAS. The processor configuration is shown in Figure 6. The VAX is a 32-bit minicomputer with a write-through cache memory that interfaces to the peripheral busses and main memory through the high speed (13.3 MB/second), synchronous backplane interconnect bus (SBI). The LAS VAX has one MB of interleaved main memory with dual controllers. A floating point accelerator hardware option is included to improve arithmetic processing rates. A UNIBUS adapter allows low-speed peripherals, such as alphanumeric terminals, to access the SBI. The six MASSBUS adapters permit high-speed peripherals, such as disc drives, to make direct memory access transfers to and from the main memory through the SBI. The DR780 interface provides a direct connection between the SBI and a high-performance peripheral, in this case the AP-180V.

Auxiliary Processor

To supplement the processing capabilities of the VAX minicomputer, the LAS has been configured to include an FPS AP-180V high-speed processor. The AP-180V is capable of performing up to 12 million floating point operations per second on 38-bit floating point operands. The LAS AP-180V configuration is shown in Figure 7 and includes 256K words of data memory, 4K words of program memory, 16K words of random access table memory, and 8K words of look-up table constants. It is expected to reduce processing time by a factor of two to five over the VAX for calculation intensive operations such as geometric correction/image resampling, classification, and other image processing functions.

High Density Digital Tape Recorders

Two 28-track Martin Marietta/Honeywell high density tape drives will provide the primary means for ingesting and archiving Landsat-D

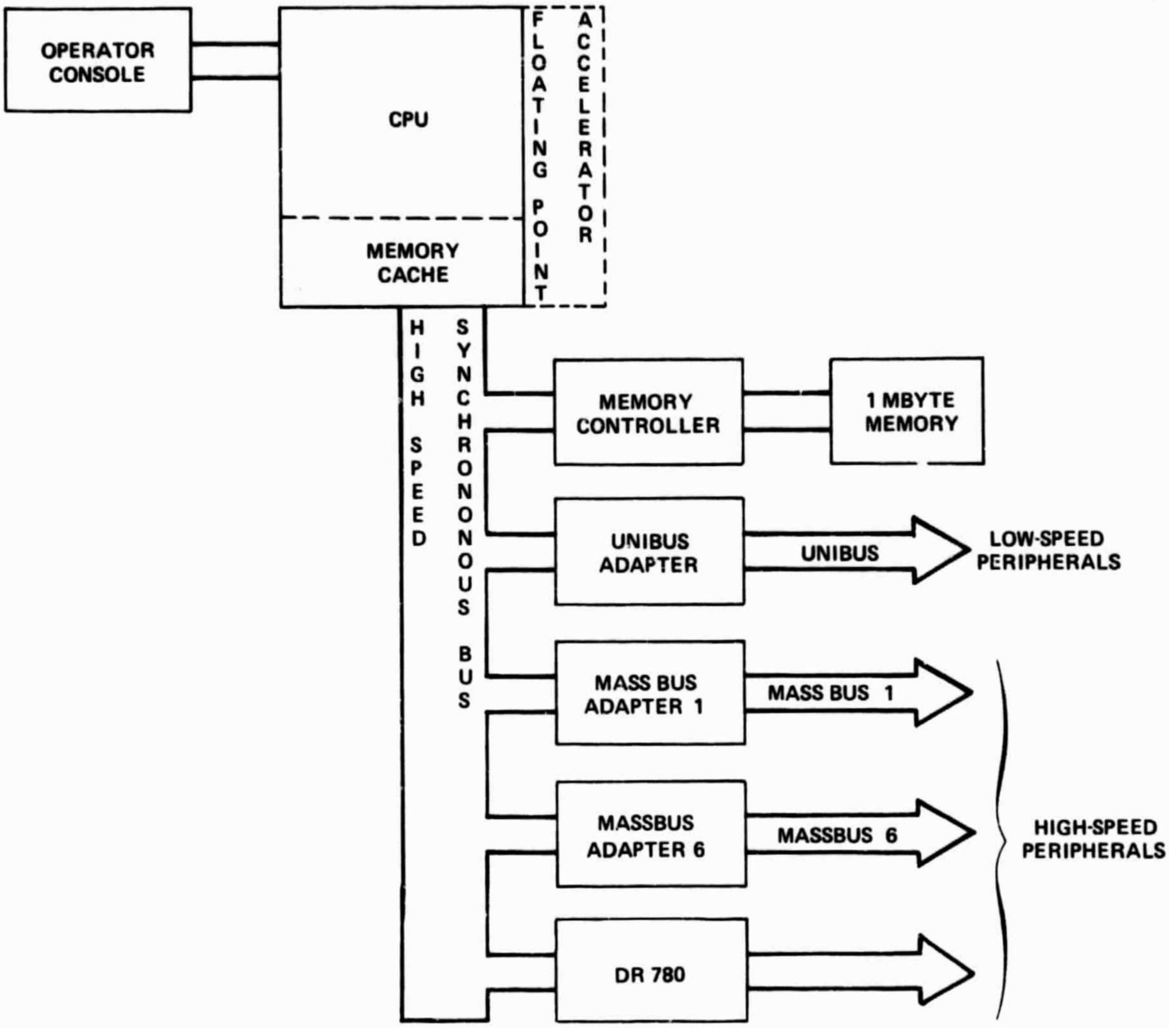

Figure 6. VAX 11/780 Processor Configuration

data. The HDDR's record data on 24 data tracks at 33,333 bits-per-inch (bpi) per track. The HDDR tape controller, built by GE for the Landsat-D Ground Segment, is shown in Figure 8.

The serial-to-parallel data input (SPDI) device performs conversion on a serial-data stream from the HDDR to a VAX acceptable format. The Crop/Subsample/Average component of the SPDI performs rectangular windowing of data, and pixel subsampling or averaging in real time. Window sizes, subsampling rates, and averaging reduction factors are selectable under software control. The parallel-to-serial data output (PSDO) device performs the inverse function of the SPDI. The HDDR hardware provides capabilities for searching tapes for a designated scene at 240 inches per second (ips) and rewinding tapes at 300 ips. The LAS SPDI and PSDO will operate at a data transfer rate of 400 KB/sec.

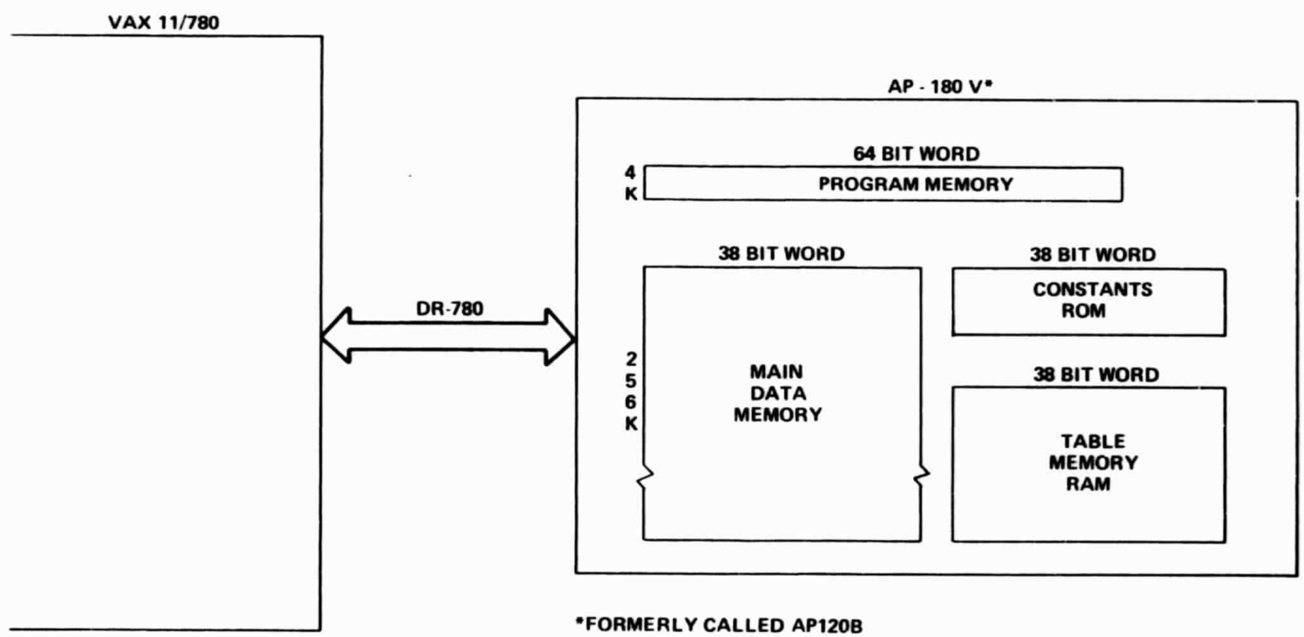

Figure 7. AP-180V Structure

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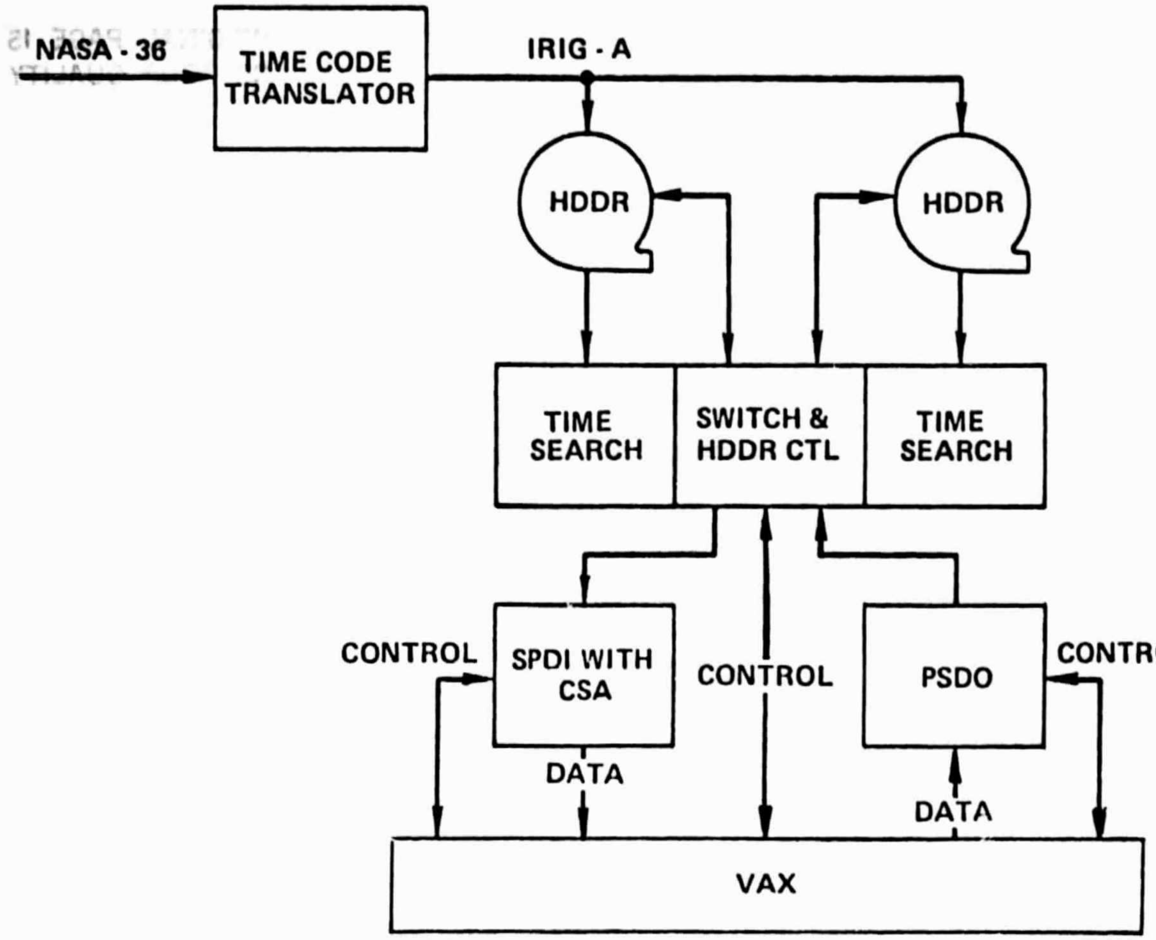

SPDI : SERIAL TO PARALLEL DATA INPUT
CSA : CROP, SUBSAMPLE, AVERAGE
PSDO: PARALLEL TO SERIAL DATA OUTPUT

Figure 8. HDTR Subsystem

Image Analysis Terminals

The three LAS image display and analysis consoles developed by the Hazeltine Corporation, model DDG-17A, are similar to existing image analysis terminals in use at GSFC. The three consoles provide interactive image processing and color image display capabilities. Each terminal includes eight solid-state television refresh memories with individual refresh channels containing 512 by 512 eight bit picture elements. (See Figure 9.) The terminals will be interfaced to the VAX computer through a MASSBUS adapter, allowing data transfer of one 512 by 512 eight-bit image in less than 1 second. Fast image manipulation is accomplished by the use of terminal hardware, including a joystick driven cursor, image shifting and windowing circuitry, gray-level look-up tables, and a switchable matrix memory configuration. System flexibility is maintained by controlling all hardware functions from the terminal driver software.

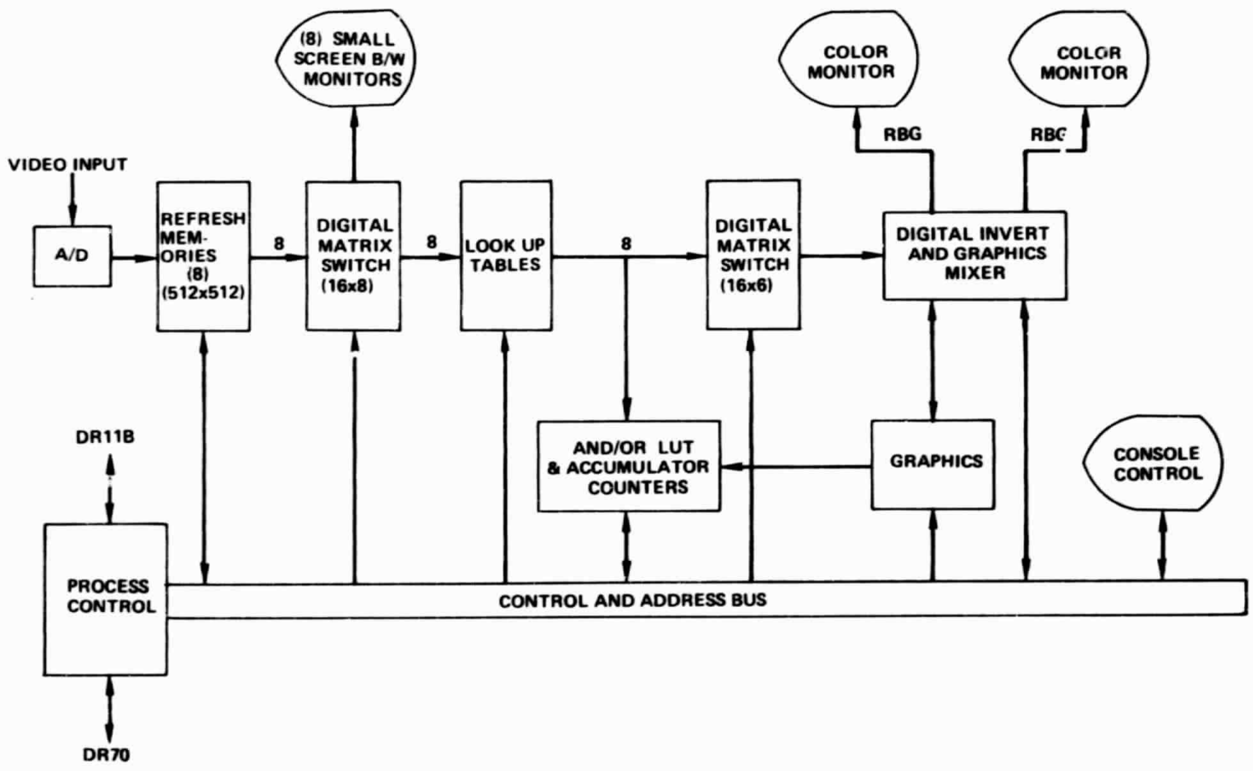

Figure 9. Image Analysis Terminal Architecture

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A vidicon scanner/digitizer unit has been developed in-house at GSFC to produce digital images of maps, photographs, graphs, etc. The unit produces standard television signal output that is converted from analog to digital by the single electronics Hazeltine IAT. The digital image is then stored in a 512 by 512 refresh memory.

Disc Storage

The LAS configuration includes eight RP06 disc drives. Four of them are dual-ported to allow multiple access paths and each provides 176 MBs of storage. These drives provide the capacity to store up to two full TM and two full MSS scenes. These units will be used for bulk storage of full and partial scenes read from high-density tapes. Of the remaining four disc drives, one will be used as the system disc and the remaining three will be dedicated to the three interactive image analysis consoles.

CCT Recorders and Other Peripherals

Two STC-1953 800/1600/6250 bpi magnetic tape drives are connected to a MASSBUS and provide capabilities for reading and writing CCTs. These units will serve for ingesting and creating data tapes and for creating tapes to be used as input to the off-line film recorder subsystem.

Several hard-copy devices, including: a Versatec printer/plotter, a DEC 300 line-per-minute line printer, and a letter quality printer, are interfaced to the UNIBUS. They will provide the ability to produce shade prints of digital image data, program listings, and documentation. Fourteen alphanumeric CRT terminals (VT 100's) are also interfaced to the UNIBUS for program development and use by applications scientists. Users will be able to obtain quick hard copy from CRT's with a Tektronix monochrome hard-copy unit and from the IAT's with a video color Polaroid hard-copy unit. In addition to these "quick-look" devices, a DICOMED D47 and an Optronics L5500 film recorder will be available. The DICOMED is capable of generating black and white and color products having dimensions of 4096 by 4096 pixels. The Optronics generates black-and-white products only, but can handle image dimensions of up to 8000 by 8000 pixels. Several black-and-white images can be pin registered to produce color composite products.

SYSTEMS AND APPLICATION SOFTWARE

The collection of software used in support of the applications programs on the LAS is termed system software. The system software will include: the host operating system and its extensions, the applications executive, data transfer utility programs, and support software for the auxiliary processor and the image analysis terminals.

Operating System

VMS (Virtual Memory System) is the DEC-supplied operating system for the VAX 11/780. It is capable of: scheduling, record and file management, and has virtual memory features. The program development tools included for VAX/VMS are test editors, a linker, a librarian, a common run-time procedure library, and a debugger. The command language for VAX/VMS (DCL) provides access to the program development utilities as well as language compilers and user system services. A MACRO assembler is a standard feature of VMS, and a FORTRAN compiler will be purchased as well. The I/O services for VMS are the record management system (RMS) for general purpose file and record processing, and the I/O system services, for direct I/O processing.

All standard peripherals, including discs, magnetic tapes, printers, card readers, and terminals are supported by the manufacturers' device drivers and diagnostics. The General Electric Company, which is responsible for building and/or integrating the IAT's and HDDR subsystem, will provide device drivers and diagnostics for these peripherals.

The International Mathematical and Statistical Library will be purchased from IMSL, Inc., to provide standard support routines callable by applications programs. Versatec, the manufacturer of the LAS electrostatic printer/plotter, will be the source of the Versaplot package. In addition, the software for the AP-180V's control and program development will be purchased with the hardware from Floating Point Systems.

Applications Executive

The LAS will use an applications executive program to provide the following:

- A user command and menu interface for control and sequencing of applications tasks
- An application program support package for passing control parameters and data to the application on demand
- Information management support, including catalog management and resource arbitration

The LAS applications executive will be the Transportable Applications Executive (TAE), which is being developed by the Information Extraction Division at GSFC.

TAE interactive services will provide a range of capabilities to meet the needs of users with all levels of expertise. Menus are generally intended for use by novice users and will serve to guide a user to available system services and processors. The command

language will provide a powerful and fast way of directing the system to carry out desired functions. The TAE Command Processor will support VICAR* commands and command syntax as a subset of the TAE Command Language.

Applications Software

The applications software is fundamental to the LAS because it provides the means for carrying out the general image analysis requirements of LIDQA investigators. The applications programs which will exist in one or more applications libraries, will be modularized to perform single functions. In addition it will be designed and implemented using the structured methods of the LAS Software Management Plan and the interface requirements of the TAE and the image data base.

LAS applications software will be based on a conversion of existing VICAR routines and will be partitioned into the following six major categories:

- Preprocessing
- Radiometric Correction
- Geometric Correction
- Image Manipulation
- Display Manipulation
- Interpretation and Analysis

However, at the time of the Landsat-D launch, all VICAR routines will not be implemented on the LAS. Applications software will be available at D launch to perform the following:

- Preprocess images to repair bad lines, image blemishes, and spikes
- Apply Fourier transforms (one and two dimensional)
- Extract subimages
- Generate histograms and print intensity values
- Generate and apply radiometric look-up tables (RLUT)
- Perform image registration and apply geometric transformations
- Resample pixel values using nearest neighbor, bilinear, or cubic-convolution interpolations
- Apply image enhancements including contrast stretch, gray-level slice, edge enhancement, and convolution

*VICAR is JPL's Video Image Communication and Retrieval System, a widely used image processing system that runs on IBM computers.

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- Apply pixel algebraic operations
- Difference two images
- Derive image statistics
- Generate and plot contours
- Manipulate training-site data and classification data
- Apply a Bayesian classifier
- Generate hard-copy film products

In addition, software to control the IAT's will be available at D launch to perform the following:

- Generate function look-up tables (LUT) and false and pseudo-color tables
- Display class maps
- Annotate images
- Blink images

In the months following the Landsat-D launch, additional software will be implemented to perform the following functions:

- Mosaic images
- Perform image algebraic operations
- Ratio two images
- Apply the Karhunen-Loeve transform
- Perform canonical analysis
- Compute transformed divergence
- Apply parallelopiped or minimum distance classifiers
- Perform clustering, uniformity mapping, texture analysis, linear discriminant analysis, and others

After launch additional software will be developed to control the IATs and perform the following:

- Track the cursor
- Scroll the images

- Polygonal site selection
- Image contouring

It is expected that nearly all of these functional capabilities will be available within 1 year after launch.

LAS USER INTERFACE

Because of the significant increase in data volume associated with the improved spectral, spatial, and radiometric resolution of the TM, the LAS was designed as a disc-oriented system. Thus, from the users point of view all image data is on-line in disc storage. Data I/O will be performed off-line by the LAS operations staff in response to a work order submitted by the user. Before a user's image analysis session, the requested data will be transferred from an archive tape onto a computer disc pack. Full TM and MSS scenes will be recorded on disc packs to provide an on-line data base. These removable disc packs will be stored at the LAS site.

When a user arrives for an analysis session the required data base will be installed on the computer in seconds, so effective work can begin immediately. Analysis sessions are expected to last approximately 2 hours. Thus, access to the system through the three IATs will allow 18 scheduled 2-hour sessions daily. This assumes two 8-hour shifts per day and 6 hours (approximately) of useful image analysis time per shift. Note that due to requirements on the LAS facility to produce one full TM scene per day to film, HDDT, and CCT's as part of the TM Early Access Program (Enclosure 3), only one shift per day will be available for LIDQA analyses during the first year following launch.

LAS PHYSICAL PLANT

Each terminal area will be furnished with desks, tables, map files, and storage cabinets. To accommodate large groups working together on a common research effort, two of the terminal areas can be opened by removing a folding partition. The third terminal area, which is designed to support larger working groups, also provides space for presentations to large audiences. Group presentations are aided by the availability of a projection screen television. The computer room, operator's room, programming room, and tape library are easily accessible from the image analysis terminal rooms. Computer programming activities will take place in a room directly adjacent to the computer area and will be easily accessible from the IAT rooms. Applications programmers will be available for consultation with

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discipline scientists as analysis software is developed. This software can be programmed in a background mode during the two regular shifts, with no impact on the LAS users interactive sessions.

THEMATIC MAPPER – AN INTERIM REPORT ON ANTICIPATED PERFORMANCE

80-1915

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Abstract

The Thematic Mapper (TM) is a second generation Earth Resources Space Sensor being developed by the Hughes Aircraft Company under a contract from NASA's Goddard Space Flight Center. The Thematic Mapper is a derivative of the Multispectral Scanner (MSS) sensors which have flown on Landsat Spacecrafts 1 thru 3. Several papers have been written describing the performance specifications and the design features of the Thematic Mapper.[1,2] This paper will briefly review the requirements and the design concept but will concentrate on the anticipated on-orbit performance based on subsystem and system level test results obtained from Engineering Model and Protoflight Model hardware.

Introduction

The Thematic Mapper (TM) is an advanced Multispectral Scanner earth resources sensor that will be launched on the National Aeronautics and Space Administration's Landsat-D satellite in 1982.

While the TM relies heavily on the technology of the Multispectral Scanner System (MSS), which has returned pictures of earth continuously since its launch on the first Landsat in 1972, it is designed to achieve higher imagery resolution, sharper color separation, improved geometric fidelity, and greater radiometric accuracy and resolution than its MSS predecessor. Further, TM data will be sensed in seven spectral bands simultaneously.

The TM will operate as it is carried in a circular, near-polar orbit at 705-km altitude; it will scan a swath of earth 185 km wide, an area determined by the orbital motion of the satellite and by the sweeping scan mirror of the instrument. Successive swaths are designed to overlap for complete surface coverage. The repeat scanning cycle of a given swath will occur every 16 days.

Table 1. Major Performance Requirements

Square-Wave Response	
(Bands 1-5, 7)	0.35 for 30 m Bars
(Band 6)	0.35 for 120 m Bars
Band-to-Band Registration	<6 m
Scan Profile Repeatability	<6 m
Along-Track Overlap/Underlap	<6 m
Swath Width	185 km
Radiometric Resolution	
(Bands 1-5, 7)	0.5-2.4% NEρ (Noise-Equivalent Reflectance)
(Band 6)	0.5 K NETD (Noise-Equivalent Temperature Difference)
Absolute Radiometric Accuracy	10%
Band-to-Band Radiometric Precision	2%
Channel-to-Channel Radiometric Precision	$< \frac{\text{RMS Noise}}{4}$
Spectral Coverage	0.45-12.5 μm
Signal Quantization Levels	256
Data Rate	84.9 Mbos
Weight	243 kg
Power	332 watts
Envelope	0.66 m x 1.1 m x 2.0 m

The satellite orbit is sun-synchronous; thus data from a given spot will be collected at the same time each day, approximately 9:30 a.m local standard time. It will be transmitted in two ways: through a direct downlink to ground stations around the world, and through relay to a central data processing facility at White Sands, NM. The relay will be accomplished through the Tracking and Data Relay Satellite System (TDRSS). Data will be processed on film and computer-compatible tapes. The mission requirements for TM are shown in Table 1.

Table 2 lists the specific spectral bands selected for TM and the radiometric resolution and principal applications of each band. This pixel size of 30 m (ground resolution) allows accurate classification of crop fields as small as 6 to 10 acres.

Table 2. Spectral Passbands

Band	Range (μm)	Radiometric Resolution	Principal Applications
1	0.45-0.52	0.8 NEρ	Coastal Water Mapping Soil/Vegetation Differentiation Deciduous/Coniferous Differentiation
2	0.52-0.60	0.5% NEρ	Green Reflectance by Healthy Vegetation
3	0.63-0.69	0.5% NEρ	Chlorophyll Absorption for Plant Species Differentiation
4	0.76-0.90	0.5% NEρ	Biomass Surveys Water Body Delineation
5	1.55-1.75	1.0% NEρ	Vegetation Moisture Measurement Snow/Cloud Differentiation
6	10.4-12.5	0.5 K NETD	Plant Heat Stress Management Other Thermal Mapping
7	2.08-2.35	2.4% NEρ	Hydrothermal Mapping

A cutaway illustration of the Thematic Mapper is shown in Figure 1; Table 3 lists the significant parameters of the TM.

Figure 1. Cutaway View of Thematic Mapper

Table 3. Significant TM Parameters.	
Orbit	Sun Synchronous 705.3 km Altitude 98.9 min Period 98.2° Inclination 16 Day Repeat Cycle
Scan	185 km Swath 7.0 Hz Rate 85% Efficiency
Optics	40.6 cm Aperture f/6 at Prime Focus 42.5 μrad IFOV, Bands 1-4 f/3 at Relay Focus, 43.8 μrad IFOV, Bands 5,7 170 μrad IFOV, Band 6
Signal	52 kHz, 3 db, Bands 1-5, 7 13 kHz, 3 db, Band 6 1 Sample/IFOV 8 Bits/Sample 84.9 Mbps Multiplexed Output

The scan mirror moves the view of the telescope back and forth across the ground track projected from the spacecraft's polar orbit as shown in Figure 2. In Figure 4 the ground track is shown subdivided into 16 raster lines as it is scanned in the cross-track

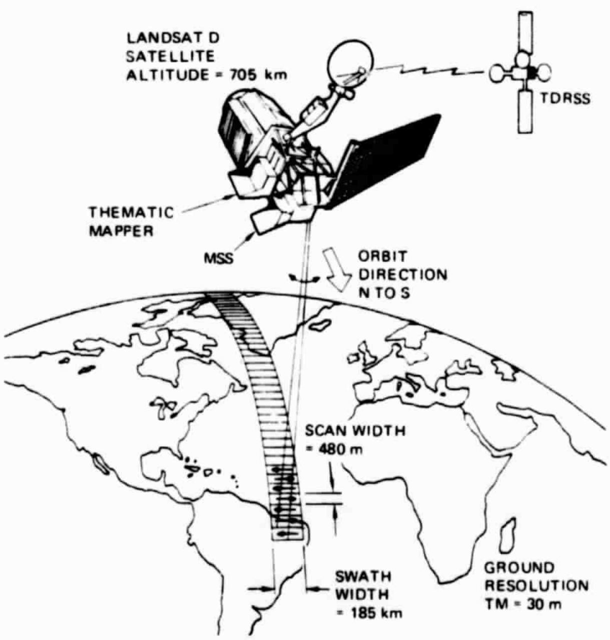

Figure 2. Landsat-D mission.

direction by an array of 16 detectors. There are six such arrays of detectors, each with an optical filter to define its spectral band; and a seventh array consisting of four detectors, each one being four times the size of a detector in the other six arrays. Figure 3 shows the precise angular relationships among the bands.

A scan line corrector preceding the detectors compensates for the southerly drift of the array's swath due to the spacecraft orbital motion, so the scan lines will be straight and perpendicular to the ground track. Figure 5 illustrates scan lines with and without this correction. Both directions of scan mirror motion can thus be used for high scan efficiency. The corrector jumps ahead during

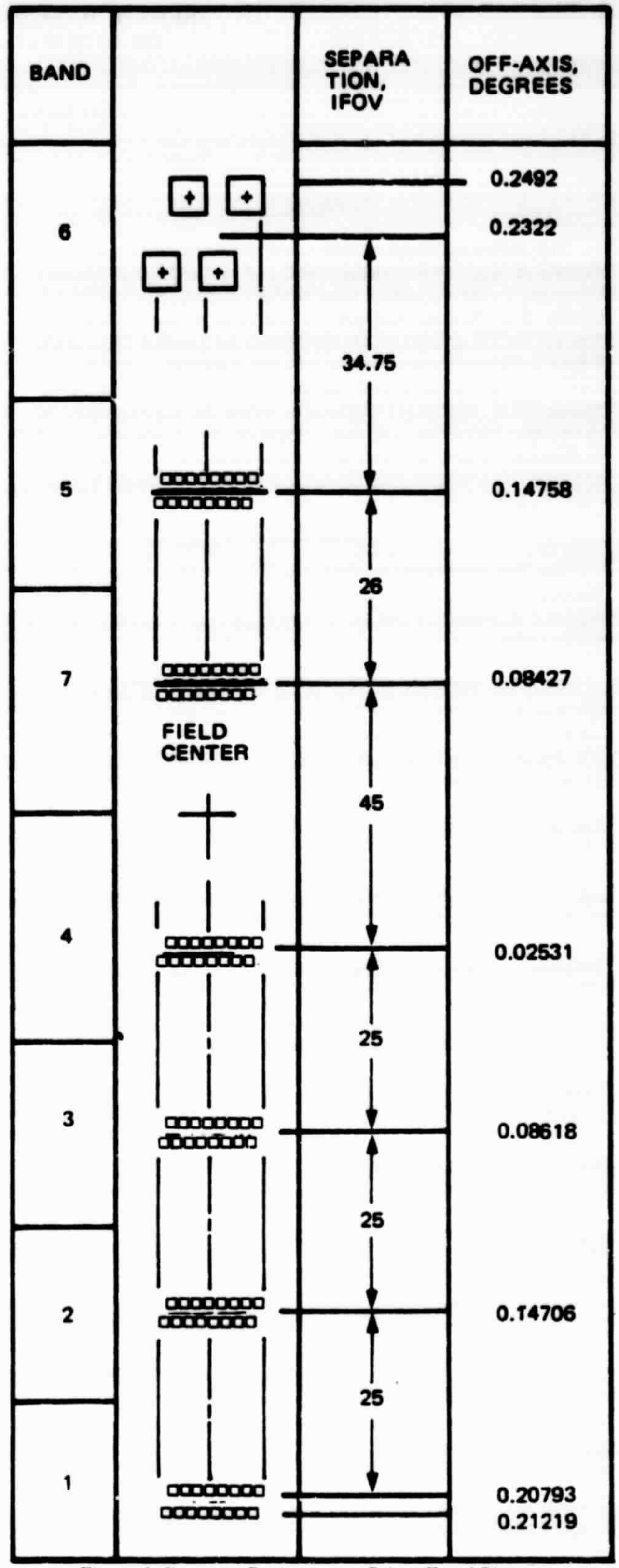

Figure 3. Detector Projection at Prime Focal Plane

the scan mirror turnaround, such that the next set of raster lines is contiguous with the previous set. Since the seven detectors representing the spectral bands in a single raster line are scanned across a fixed point on the earth's surface at seven different times, time-registration is also important. The scan mirror is constrained to move linearly and repeatably in order to satisfy this need.

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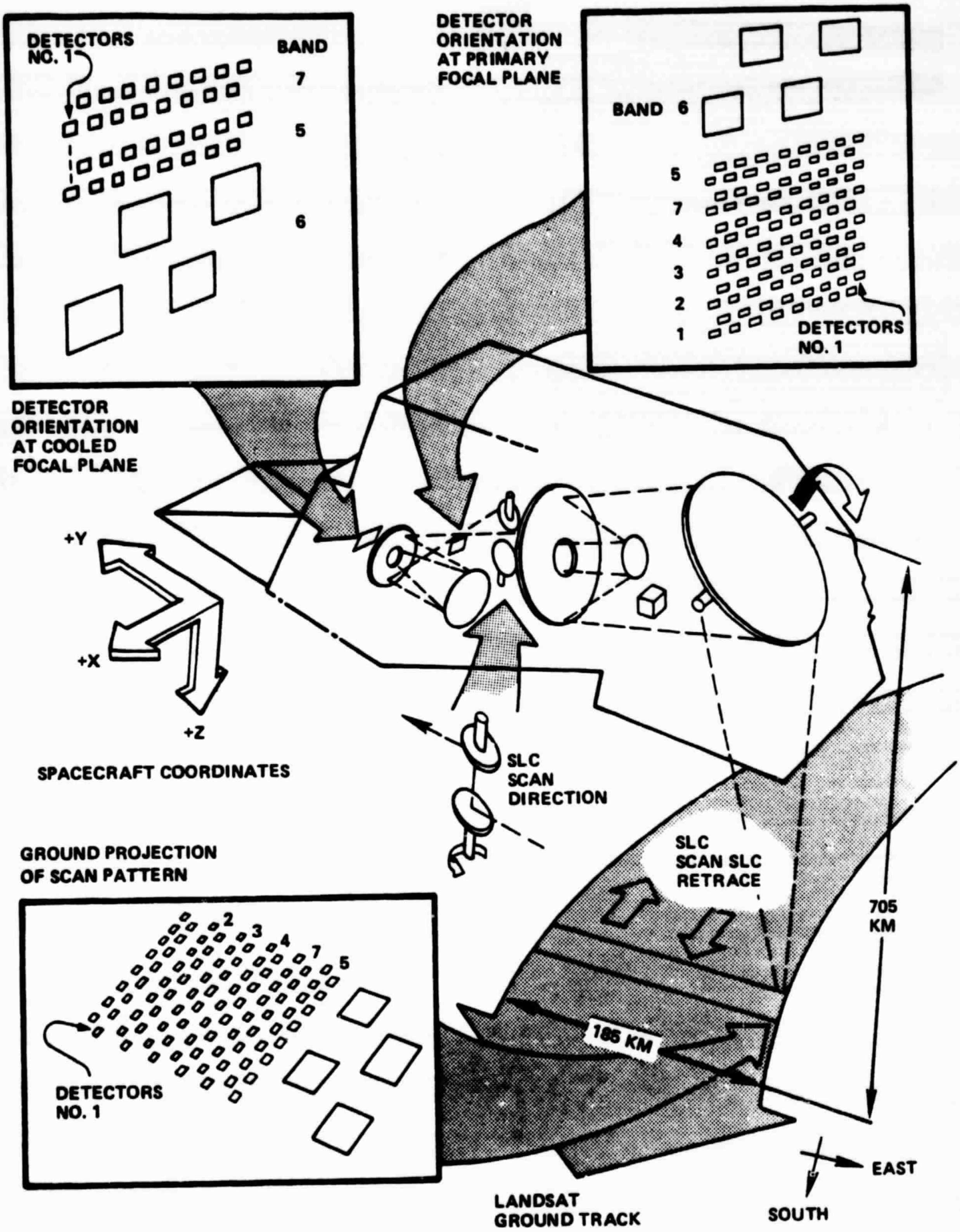

Figure 4. Detector Array Projections on Ground Track

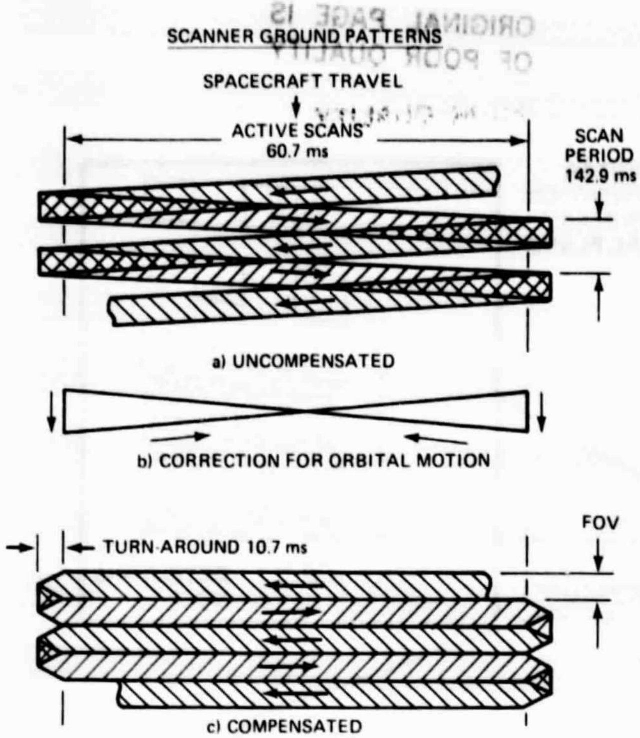

Figure 5. Scan line corrector function.

Three of the spectral bands use detectors requiring cooling. The scene energy for these passes through the prime focal plane and is refocused by relay optics at the cooled focal plane. Cooling is accomplished by a radiative cooler coupling this focal plane to space background. Radiometric calibration of the instrument is maintained by passing a shutter just ahead of the telescope's prime focal plane during scan mirror turnaround. The shutter presents to the detectors first a black reference surface and then, toward one edge, an optical system transmitting energy from reference sources. Tungsten lamps are the calibration sources for bands 1 through 5 and 7, while band 6 views a heated blackbody in a mirror mounted on the shutter.

The reasons for some basic choices of the TM design are:

1. Object-space scanning uses relatively small field angles in the optics, thus giving the advantages of minimum optical aberrations and of minimum obscuration by the secondary mirror.
2. All-reflective optics (except for cooler windows) enable wide spectral coverage.
3. Separation of the spectral bands by focal plane spacing allows much of the band-to-band registration to be attained by co-planar adjustment of the detectors.

Program Status

The design phase of the Thematic Mapper program has been completed and the Engineering Model is undergoing system performance testing. The subsystems for the Protoflight Thematic Mapper are being integrated into the final configuration, and system performance testing will begin in December, 1980. It will be delivered to NASA in September, 1981 and is scheduled for launch on the Landsat D Spacecraft in 1982. The subassemblies for the Flight I Thematic Mapper are being assembled and the Flight I instrument is scheduled for delivery to NASA in September, 1982.

The remainder of this paper will provide, 1) a review of the design of each of the major subsystems of the Thematic Mapper including photographs of the flight hardware followed by 2) a look at the anticipated performance of the Thematic Mapper with respect to the system requirements for spectral response, radiometric sensitivity, square wave response, and band-to-band registration.

Subsystem Design

In this section the function and design features of the major subsystems are reviewed in the sequence in which the scene energy passes through the optical system beginning with the object space scan mirror assembly.

Scan Mirror Assembly

The beryllium scan mirror is required to operate linearly over a mechanical scan angle of 7.7° at a 7-Hz rate with the required turnarounds occurring in 10.7 msec. Figure 6 illustrates the scan mirror angular position as a function of time. The linearity of

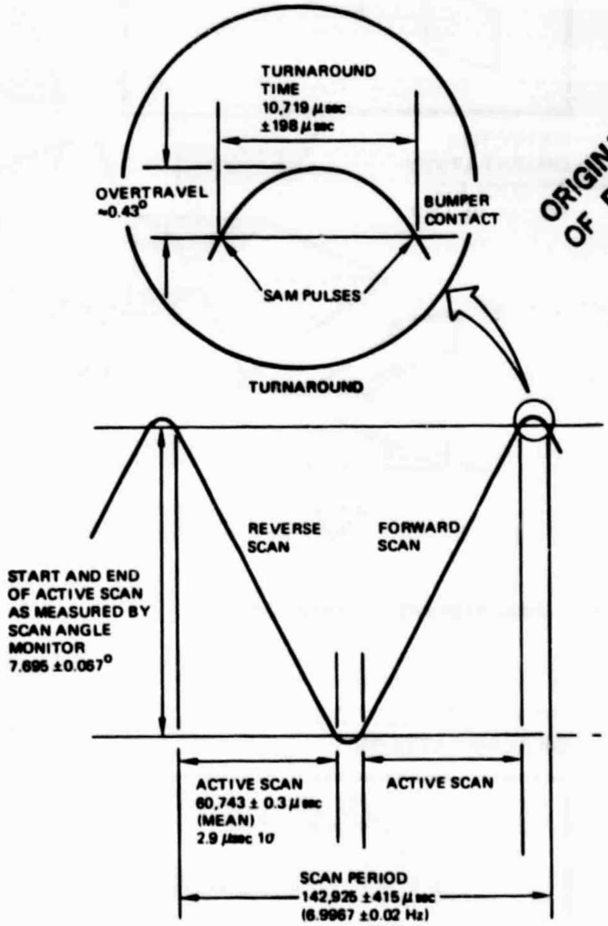

Figure 6. Scan mirror assembly operational requirements.

motion during the active scans (forward and reverse) is extremely important due to the effects of a nonconstant velocity on the stringent band-to-band registration requirements. The band-to-band registration performance budget allocation for the scan mirror, requires the scan profile to be linear to within 17.5 μrad peak over the full scan angle. The scan mirror is elliptical in shape with a major diameter of 21.05 inch and a minor diameter of 16.25 inch The size of the mirror requires that a light brazed-beryllium egg-crate structure be used to minimize the mass and moment of inertia of the structure making these turnarounds.

The mirror operation consists of a nearly inertially-floating scan with scan reversal caused by the mirror striking leaf spring

bumpers. A computed torque is applied during the reversal interval to maintain the active scan time precisly. The torque computation uses timing information from a scan angle monitor sensing the instants when the mirror angle passes start, center, and end of scan.

The mirror rotates on flex pivots which have some restoring torque. This is countered by a magnetic compensator, and a resultant eddy current drag is offset by a small square wave of current to the torquer, constant during the scan. The scan mirror is shown in Figure 7, and a summary of some of the design parameters is given in Table 4.

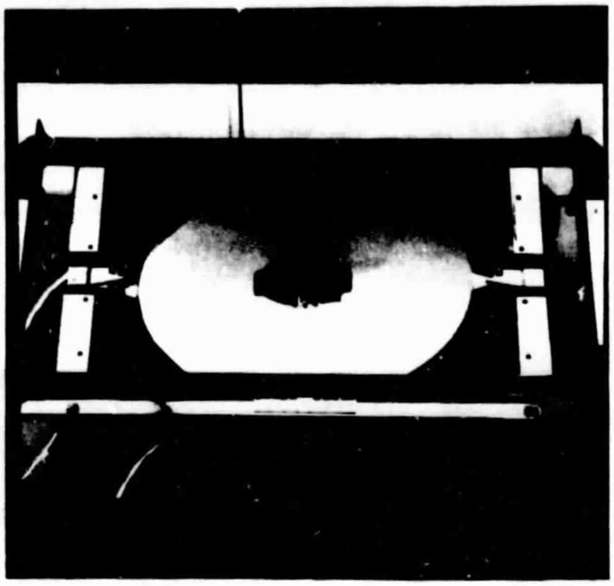

Figure 7. Scan Mirror Assembly.

Table 4. Scan Mirror Assembly

Swath Length	185 km
Scan Period	142.925 msec
Scan Frequency	6.9967 Hz
Scan Efficiency	0.85
Active Scan Time	60.743 msec
Turnaround Time	10.719 msec
IFOV Dwell Time	9.611 sec
Line Length	6320 IFOV
Size	21.050 x 16.250 In. (53.47 x 41.28 cm)
Material	Nickel-plated Beryllium (Eggcrate) Silver Coating with SIO_2 Protective Overcoat

Primary Telescope

The Ritchey-Chretien telescope uses primary and secondary mirror surfaces of a hyperbolic figure to provide for simultaneous correction of spherical aberration and coma. This permits essentially perfect geometric image quality on-axis and a well-corrected image off-axis.

An f/6 design was chosen to allow reasonable detector sizes; e.g., a 42.5-μrad detector is 0.00408 inch across. This is large enough to permit close control of tolerances yet small enough to keep detector noise low. The focal plane of the detector is 8 inches to the rear of the primary mirror vertex. Allowing for primary mirror thickness, the spacing is adequate to permit installation of the scan line corrector and calibrator optics between the primary mirror and the focal plane.

The primary and secondary mirrors have been fabricated from ultra-low expansion (ULE) glass (ULE titanium silicate). ULE has all the desirable mirror qualities of fused silica and, in addition, exhibits a thermal expansion coefficient of essentially zero over a wide temperature range of either side of room temperature.

Mechanical design considerations had indicated the need for lightweight mirrors to enhance the overall structure stiffness-to-weight ratio. A suitable primary mirror has been formed using an eggcrate structure, obtaining a weight reduction of approximately 60% over a comparable solid mirror blank. The tubular structure which supports the primary telescope mirror, as well as all the other critical components in the optical train including the radiative cooler for the cooled focal plane detectors, is fabricated using graphite epoxy composite materials. The graphite composite structure has a very high stiffness-to-weight ratio and provides an excellent thermal expansion match with the ULE glass mirrors. The primary telescope assembly is shown in Figure 8 with a summary of parameters given in Table 5.

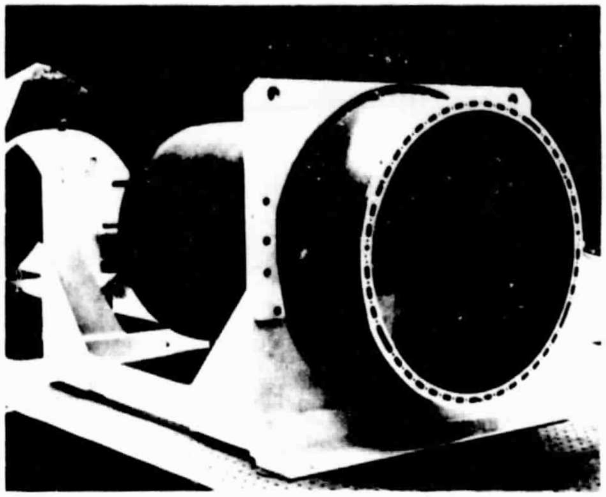

Figure 8. Primary Telescope Assembly.

Table 5. Primary Telescope

Configuration	Ritchey-Chretien
f / No.	6.0
Mirror Material	ULE Glass (Titanium Silicate), Silver Coating with SIO_2 Overcoat
Primary Mirror Clear Aperture Diameter	16.20 In. (41.15 cm)
Secondary Mirror Baffle Diameter (Obscuration)	6.173 In. (15.7 cm)
Telescope Clear Aperture	1063 cm^2
Effective Focal Length	96 In. (243.8 cm)
Protoflight	96.010 In.

Scan Line Corrector

The scan line corrector (SLC) is located between the primary mirror and the prime focal plane. As indicated earlier, it must create a linear image displacement during the active scan time of the scan mirror assembly to compensate for spacecraft motion, and produce bi-directional scan swaths without overlap and underlap at the ends of scan. The SLC is shown in Figure 9. A pair of plane parallel beryllium mirrors mounted at an angle of 45° with respect to the optical axis rotate about an axis normal to the axis of the scan mirror in a sawtooth fashion as shown in Figure 10. The rotational amplitude and other SLC parameters are given in Table 6.

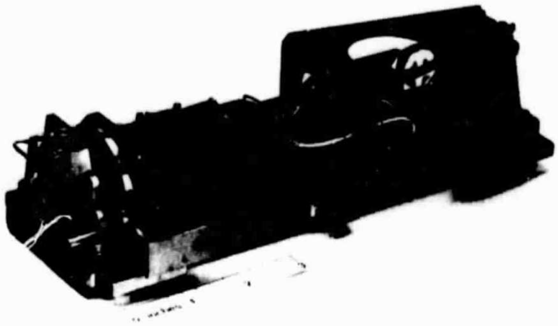

Figure 9. Scan Line Corrector Assembly.

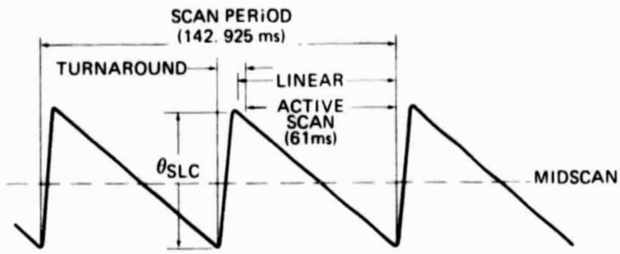

Figure 10. SLC motion.

Table 6. Scan Line Corrector

Scan Frequency	13.9934 Hz
Scan Period	71.462 msec
Scan Rate in Object Space	9.610 mrad/sec
SLC Rotation Rate	576.6 mrad/sec
SLC Linear Scan Angle	35.02 mrad
Mirror Separation	1.600 In. (4.064 cm)
Linear Image Displacement Amplitude	0.056 In. (0.142 cm) (13.7 IFOV)
Mirror Material	Nickel-plated Beryllium, Silver Coating with SIO_2 Overcoat

Prime Focal Plane

The prime focal plane which contains the silicon detectors and critical preamplifier components for the first four spectral bands is located at the prime focus of the primary telescope.

The prime focal plane is packaged in the high-density configuration as shown in Figure 11 to minimize the band-to-band spacing. This limits the effects of velocity variations of the scan mirror on dynamic band-to-band registration as well as minimizing the field angle over which the primary telescope must maintain high image quality. The band-to-band spacing of 0.1 inch dictated that the critical first-stage preamplifier FETs and 10^9 Ω feedback resistors be located on substrates behind and normal to the focal plane. This is to minimize lead lengths and input node capacitance, thereby maximizing S/N performance.

The remainder of the less critical preamplifier components are mounted in hybrid circuits which are connected to the focal plane through flexible cables. The 16-element monolithic silicon detector arrays, the substrate assembly containing the FETs and feedback resistors, and three successive levels of assembly are shown in Figures 12 through 16. Table 7 summarizes some of the design parameters of the prime focal plane.

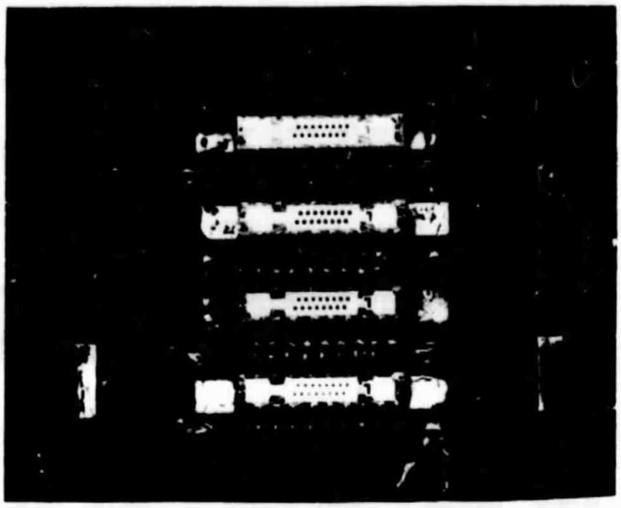

Figure 11. Enlarged View of Prime Focal Plane Before Installation of Spectral Filters.

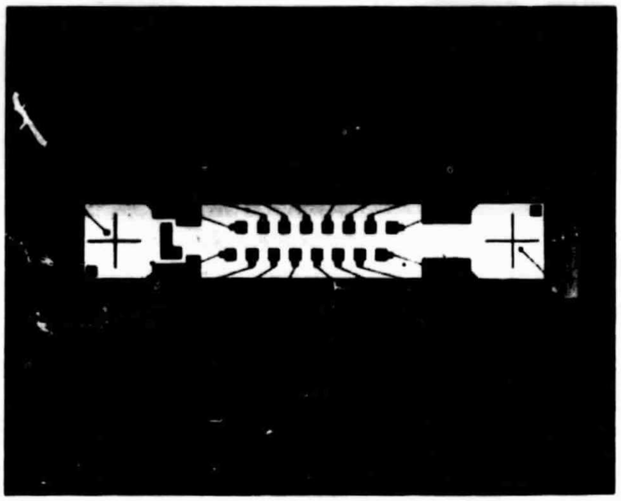

Figure 12. Monolithic Silicon Detector Array.

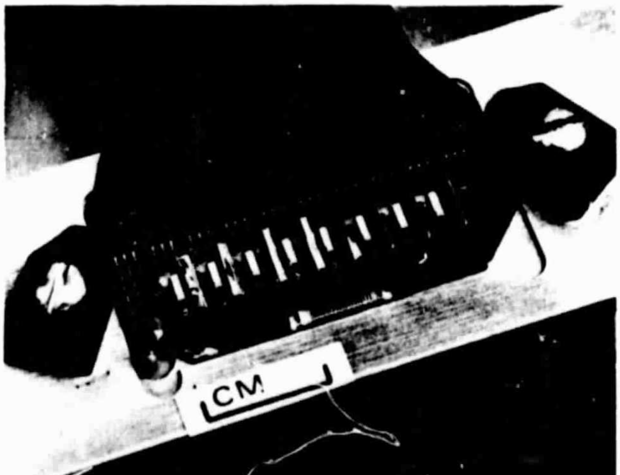

Figure 13. Prime Focal Plane Substrate Assembly.

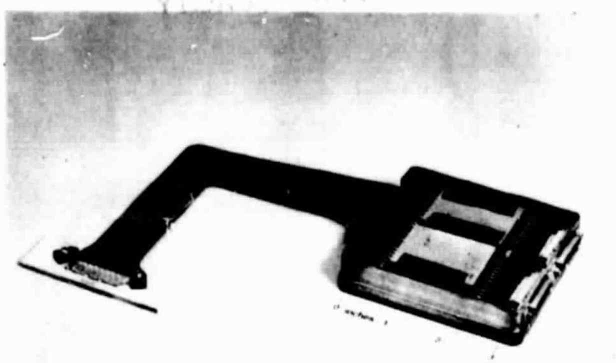

Figure 14. Prime Focal Plane Half-Band Assembly.

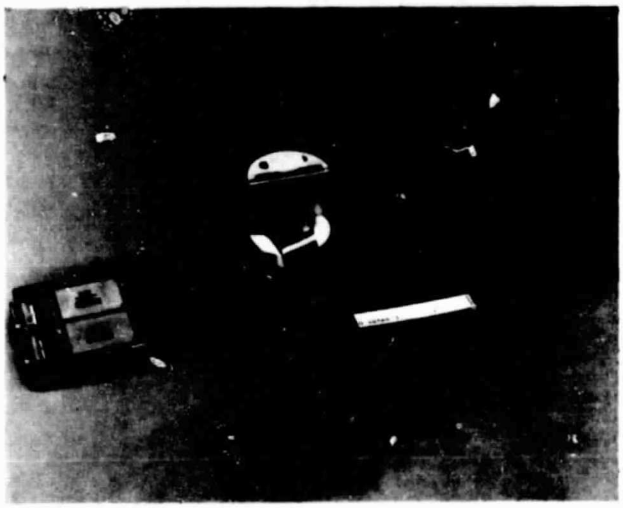

Figure 15. Prime Focal Plane Band Level Assembly.

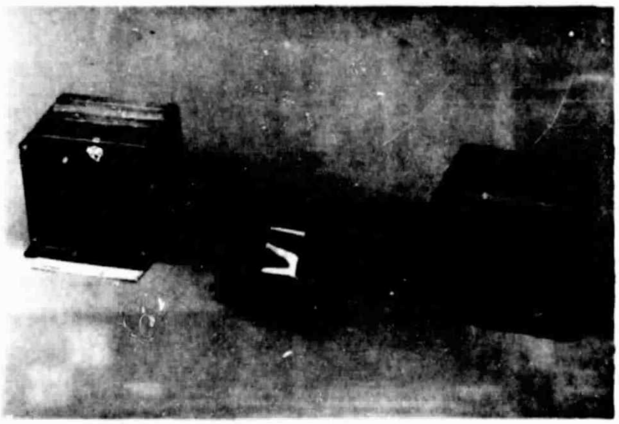

Figure 16. Prime Focal Plane Assembly.

Relay Optics

Two mirrors, a folding mirror and a spherical mirror, are used to relay the image from the primary focal plane to the cooled focal plane. The two-mirror relay, shown in Figure 3, was adopted over other designs because of confidence in performance. The components are simple and easy to fabricate and assemble.

Table 7. Prime Focal Plane Assembly

Number of Bands	4
Number of Detectors (Monolithic Silicon)	16/Band
Detector Size	0.00408 In. sq (0.01036 cm sq)
IFOV Size	42.5 μrad
Band-to-Band Spacing	0.102 In. (0.259 cm) (25 IFOV)
Center-to-Center Spacing In Each Row	0.00816 In. (0.0207 cm) (2 IFOV)
Center-to-Center Spacing Between Rows	0.01020 In. (0.0259 cm) (2.5 IFOV)
Operating Temperature	10° to 25°C

A fourth order aspheric term on the relay folding mirror is effective in improving the image quality of the relay. Likewise, the tilt and offset values applied to the relay elements are necessary to produce a good image in the tilted cooled focal plane. Equally important, however, is the fact that the tilts and decenters put the energy through the hole in the folding mirror without vignetting at any field angles. The folding mirror is tilted 12.8° from the telescope axis while the center of the spherical mirror is tilted an additional 12.2° from the axis. The tilt is introduced for the purpose of making the convergent optical axis parallel to the axis of the radiative cooler.

The relay optics are shown in Figure 17. The two mirrors are mounted in a graphite composite structure. The cylindrical assemblies that are located on 120° centers around the lower section

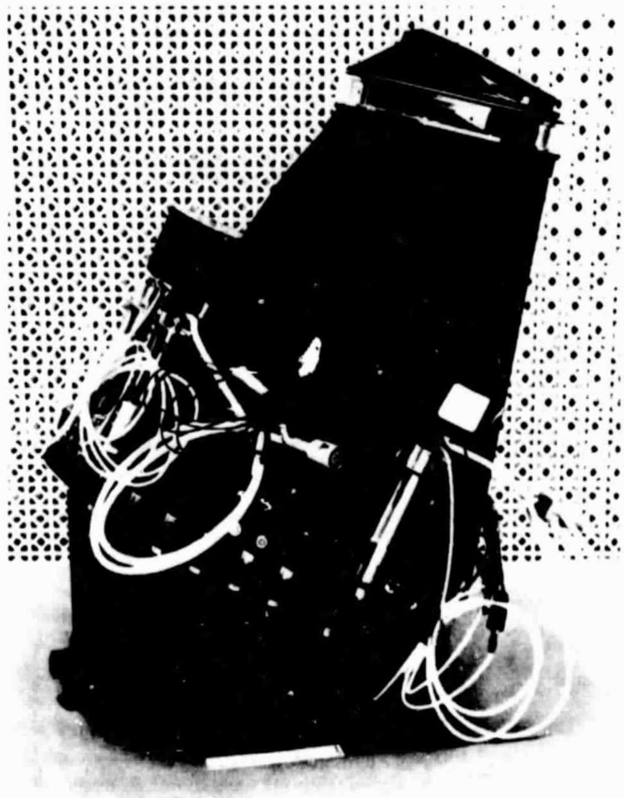

Figure 17. Relay Optics Assembly.

of the assembly are mechanisms which provide a capability for on-orbit alignment and focus of the cooled focal plane (bands 5-7) with respect to the prime focal plane. Table 8 summarizes the relay-optics parameters.

Table 8. Relay Optics Assembly

Outer Diameter of Folding Mirror Clear Aperture	3.14 In. (7.98 cm)
Inner Diameter of Folding Mirror Clear Aperture	0.537 In. (1.36 cm)
Spherical Mirror Clear Aperture Diameter	5.538 In. (14.067 cm)
Magnification	0.5
f/1 No.	3.0
Material	ULE Glass (Titanium Silicate), Aluminum Coating with SiO_2 Overcoat

Cooled Focal Plane

The cooled focal plane which contains the indium antimonide (InSb) detectors for bands 5 and 7, and the mercury cadmium telluride (HgCdTe) detectors for band 6 are located in the radiative cooler at the image plane of the relay optics. Also located in the cooled focal plane are the first-stage pre-amplifier FETs and $2 \times 10^8\ \Omega$ feedback resistors for the high-impedance InSb detectors. The HgCdTe detectors are low-impedance devices ($\approx 50\Omega$), therefore need no preamplification on the focal plane. Figure 18 shows the cooled focal plane substrate with all components mounted. Figure 19 shows the focal plane with spectral filters in place mounted in the center of a distribution board.

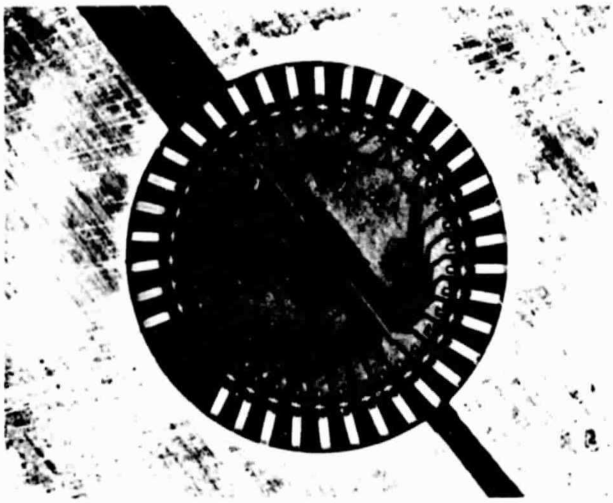

Figure 18. Cooled Focal Plane Substrate Assembly.

Focal plane signals are brought off the distribution board by very thin, flexible, low thermal conductance cables to preamplifiers which are mounted in a housing bolted to the ambient structure of the radiative cooler. The cooled focal plane also has a thin-film heater which maintains the focal plane temperature within ± 0.2 K of three selectable temperatures, 90 K, 95 K and 105 K. Figure 20 shows the cooled focal plane mounted in the radiative cooler. Figures 21 and 22 show the InSb and HgCdTe detectors. Table 9 summarizes the design parameters.

Radiative Cooler

The radiative cooler shown in Figure 23 provides cooling for the bands 5 through 7 detectors. The design uses two cooling stages with open faced honeycomb for the radiator emitting surfaces. The radiators are shielded from direct view of the sun, earth, or spacecraft surfaces. The cold-stage radiator sees only cold space and IR emissions from a cooled radiation shield mounted on the intermediate stage. Earth energy is shaded from the intermediate stage radiators by a deployable earth shield which also serves as a protective door. Diffusely reflected solar energy and IR emissions from the earth shield fall only on the intermediate stage radiator.

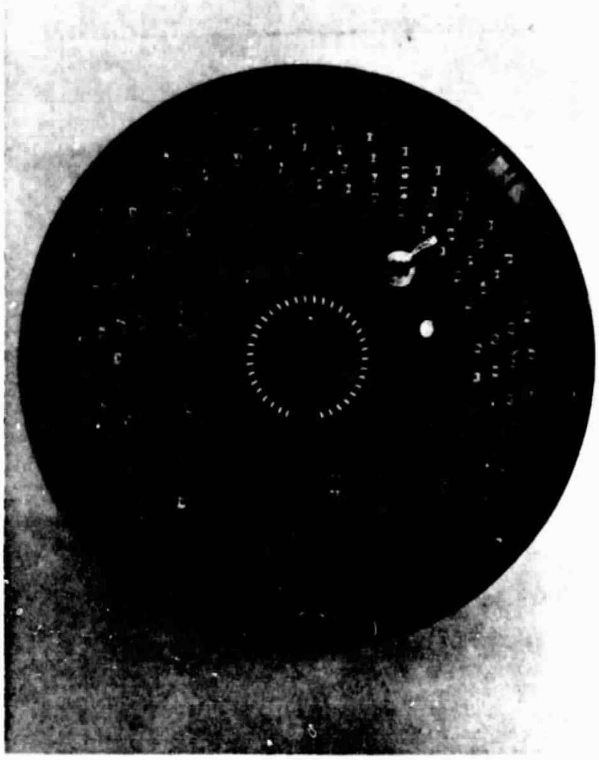

Figure 19. Cooled Focal Plane and Distribution Board.

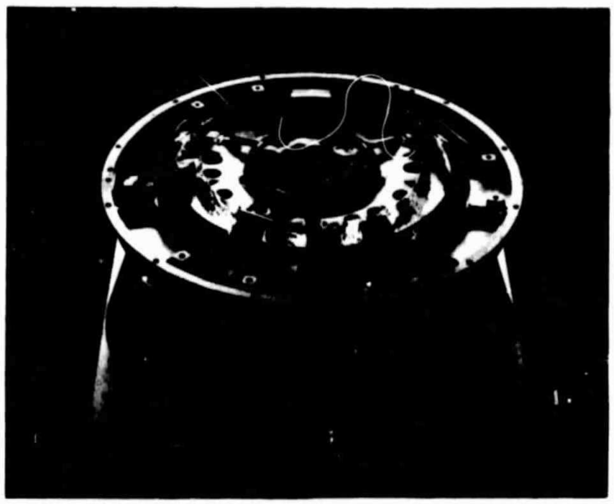

Figure 20. Cooled Focal Plane in Radiative Cooler.

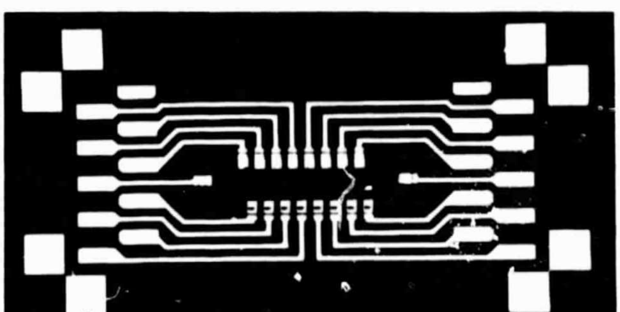

Figure 21. Monolithic Indium Antimonide Detector Array.

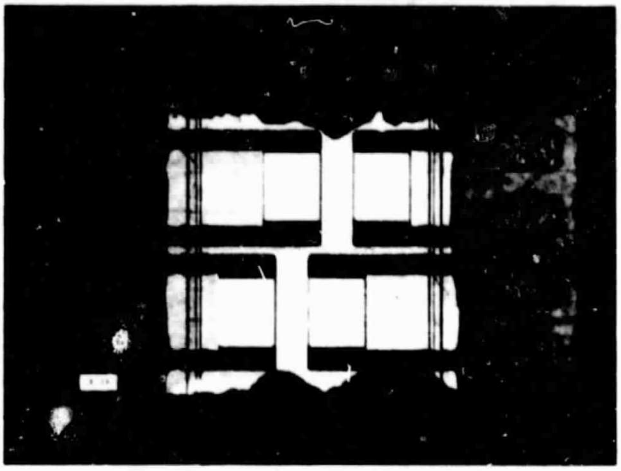

Figure 22. Mercury Cadium Telluride Detector Array.

Table 9. Cooled Focal Plane Assembly.

Number of Bands	3
Number of Detectors	
Bands 5, 7 (Monolithic InSb)	16/Band
Band 6 (Photoconductive HgCdTe)	4
Detector Size	
Bands 5, 7	0.0021 In. sq (0.00533 cm sq)
Band 6	0.00816 In. sq (0.0207 cm sq)
IFOV Size	
Bands 5, 7	43.75 μrad
Band 6	170.0 μrad
Center-to-Center Spacing in Each Row	
Bands 5, 7	0.00408 In. (0.01036 cm) (2 IFOV)
Band 6	0.01632 In. (0.04145 cm) (2 IFOV)
Center-to-Center Spacing Between Rows	
Bands 5, 7	0.00510 In. (0.01295 cm) (2.5 IFOV)
Band 6	0.02040 in. (0.0518 cm) (2.5 IFOV)
Operating Temperatures	90K, 95K, 105K

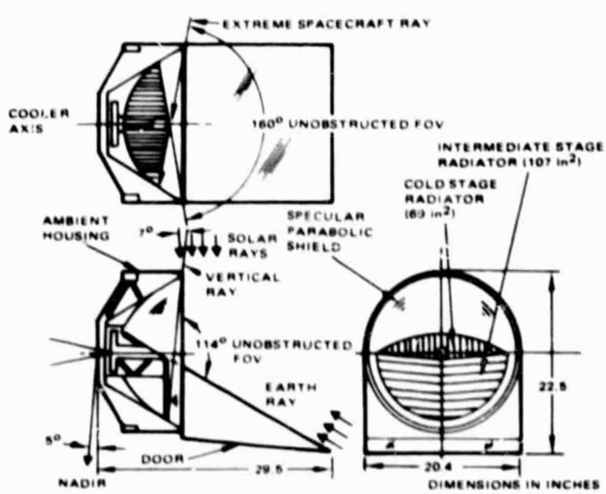

Figure 23. Cooler Schematic Showing Field of View

Tests of the cooler in vacuum with a simulated space background have shown it to be capable of reaching the specified 84.5° K temperature with bias power applied, when the temperature controller is off.

The radiative cooler for the Thematic Mapper is a derivative of the two-stage coolers flown on the Visible Infrared Spin Scan Radiometers (VISSR) aboard the SMS and GOES Meterological Spacecraft since 1974.

Figure 24 shows the TM radiative cooler looking at the radiator surfaces and their reflection in the intermediate stage specular shield.

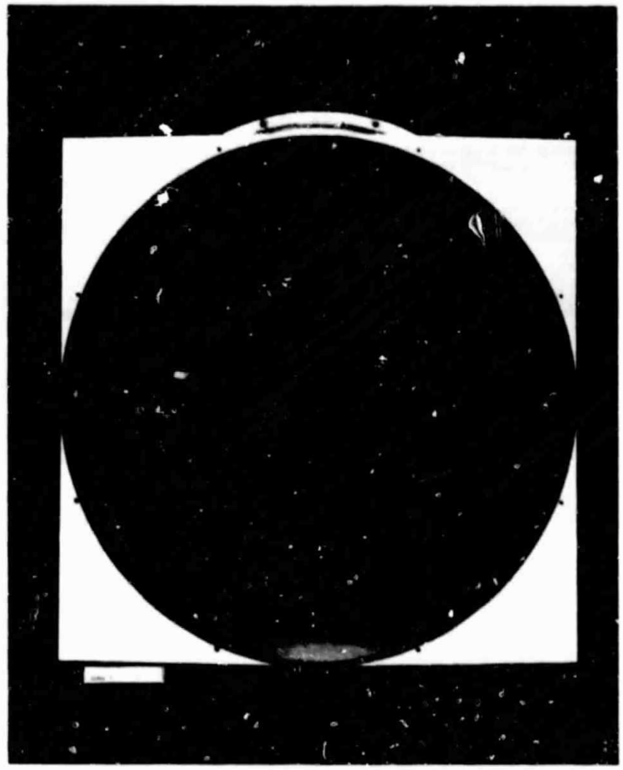

Figure 24. Radiative Cooler Radiators and Specular Shield.

Table 10 summarizes the radiative cooler design parameters.

Table 10. Radiative Cooler.

Horizontal Field of View	160°
Vertical Field of View	114°
Intermediate Stage Radiator Area	660 cm²
Cold Stage Radiator Area	430 cm²
Cold Stage Minimum Temperature Capability (All Bands On)	84.4K
Radiation Surface	Black Painted Honeycomb
Intermediate Stage Temperature	>147K
Intermediate Stage Heat Load	2.2 watts
Cold Stage Heat Load	117 mw

On-Board Calibrator

The on-board calibrator consists of three miniature tungsten filament lamps (for band 1-5, and 7), a blackbody (for band 6), and a flex pivot mounted resonant shutter. The calibrator is mounted just in front of the prime focal plane. The shutter oscillates at the same frequency (≈ 7 Hz) as the scan mirror

assembly and in phase lock with the scan mirror. In this manner the shutter introduces the calibration source energy and a black dc restoration surface into the detector fields of view during the turnaround time of each scan mirror cycle. The three calibration lamps are automatically sequenced to provide eight calibration levels (seven + dark) to all detectors of bands 1-5 and 7.

To assure uniform illumination over an area which is adequate to allow a calibration without interference with either the dc restore function or any portion of the active scan of the scene, it is necessary to have a precisely defined area illuminated without stray radiation in the surrounding areas. Therefore, an imaging scheme has been used on the output end of the shutter.

By use of fiber optics to allocate and to transfer the radiation to the separate bands, it is possible to more precisely and independently adjust the illumination in the different bands.

Figure 25 shows the on-board calibrator shutter assembly. Table 11 summarizes some of the design parameters.

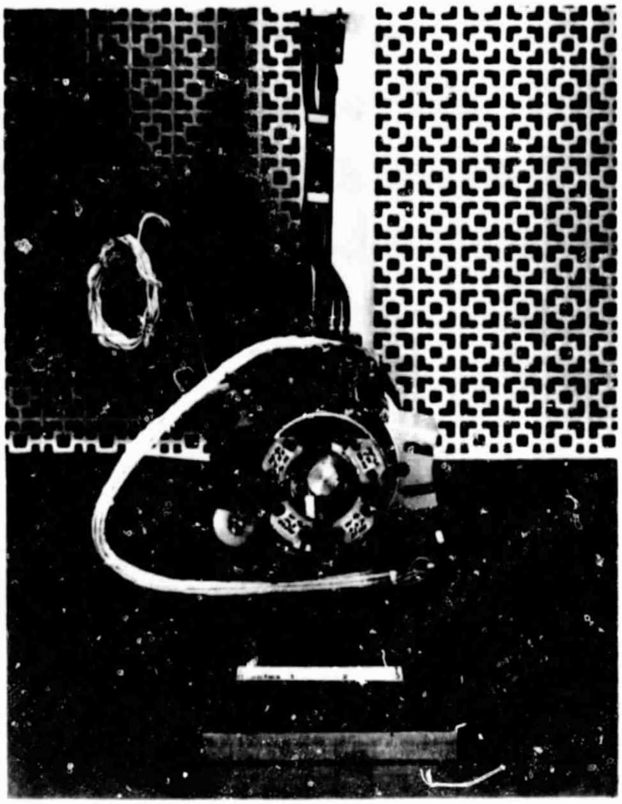

Figure 25. On-Board Calibrator.

Table 11. On Board Calibrator (And DC Restore Shutter)

Calibration Frequency	13.9934 Hz (Each Scan Mirror Turnaround)
Configuration	Pivot Mounted Shutter
Resonant Frequency	6.9967 Hz
Number of Calibration Levels	7 + Dark – Automatically Sequenced
Number of Scans at Each Level	40 (Approximately 3 sec)
Band 6 Calibration	Mirror on Shutter Reflecting Blackbody Energy. Three Controllable Temperatures
DC Restore	Each Turnaround (Before Calibration After Forward Scan; After Calibration, After Reverse Scan)
Number of Samples	Approximately 90 Samples per Scan

Electronics Module

The electronics module houses the power supply; the printed wiring boards containing the drivers and control electronics for all the mechanisms and heaters; the command and telemetry distribution and collection circuitry; the signal processing post amplifiers which limit the system frequency response; and the multiplexer. The multiplexer encodes all the radiometric data and telemetry information into 8-bit words which form an 85 MBPS data stream. The data stream will be transmitted to earth by the Landsat D Spacecraft. The Multiplexer also synchronizes all the system timing signals.

Performance

This section discusses the anticipated performance of the Thematic Mapper in four key areas: 1) spectral response, 2) radiometric sensitivity, 3) square-wave response (modulation transfer function), and 4) band-to-band registration. The performance discussed in each area is that expected to be achieved at the system level for the Protoflight Thematic Mapper, scheduled to be launched on the Landsat D spacecraft in 1982. The indicated levels of performance are based on calculated extrapolations of measurements made on protoflight components and subsystems, and also on system level measurements of the Engineering Model.

Spectral Response

The spectral response of the Thematic Mapper is shown in Table 12. The performance indicated is based on measurements of all protoflight components (mirrors, spectral filters, windows, and detectors) which affect the spectral coverage of the system.

Table 12. Spectral Response.

	Requirement (50% Response)		Measured (50% Response)	
Band	Lower Band Edge	Upper Band Edge	Lower Band Edge	Upper Band Edge
1	0.45 ± .01	0.52 ± .01	0.452	0.518
2	0.52 ± .01	0.60 ± .01	0.526	0.609
3	0.63 ± .02	0.69 ± .01	0.624	0.693
4	0.76 ± .02	0.90 ± .01	0.776	0.906
5	1.55 ± .02	1.75 ± .02	1.568	1.784
6	10.40 ± .10	12.50 ± .10	10.420	11.610
7	2.08 ± .03	2.35 ± .03	2.097	2.347

Table 13. Radiometric Sensitivity

Effective Aperture 1063 cm²
Effective Quantizer Bits 7.75

Band	Optical Transmission	Responsivity (A/W)	Fixed Noise (pA)	SNR			
				Min Scene Radiance		Min Saturation Scene Radiance	
				Prediction	Specified	Prediction	Specified
1	0.77	0.33	2.3	44	32	150	85
2	0.77	0.40	2.3	40	35	235	170
3	0.90	0.45	2.1	35	26	205	143
4	0.76	0.56	2.2	33	32	305	240
5	0.69	1.2	4.9	25	13	155	75
7	0.65	1.6	4.8	18	5	143	45
6	0.53	15 kV/W		NETD-0.1K	0.5K	0.1K	0.42K

The spectral filters dominate the response of all bands except band 6 where the upper band edge is governed by the cutoff wavelength (λ_c) of the mercury cadmium telluride detectors. The spectral content of band 6 is relatively unimportant as long as sufficient scene energy is gathered to produce an accurate determination of scene temperature. This is the case as seen in the following discussion under Radiometric Sensitivity.

The spectral responses of all other bands (1-5 and 7) meet the band edge requirements with the exception of the long-wavelength edge of band 5 which exceeds the specifications by 0.014 μm.

Radiometric Sensitivity

The anticipated performance in the area of radiometric sensitivity is indicated in Table 13. The anticipated signal-to-noise ratios (SNR) for two levels of scene radiance are shown for bands 1-5 and 7, while for band 6 the noise equivalent temperature difference (NETD) is shown for a 300 K scene and a 320 K scene. The minimum saturation scene radiance levels are tabulated in Table 14. The specified SNRs have been derived from the NEρ requirements of Table 2.

All factors affecting the signal and noise performance of the system have been considered. For purposes of the calculations, all signal and noise sources have been referred to the preamplifier inputs. The factors affecting the signal levels are: 1) the effective aperture of the 16-inch telescope (1063 cm² excluding the portion obscured by the secondary mirror and its support members), 2) the measured reflectance of all optical surfaces and the transmittance of the spectral filters and windows (in the case of bands 5-7), and 3) the measured values of detector responsivities. The factors affecting the noise level in each spectral band are: 1) the fixed preamplifier noise, 2) the signal generated shot noise, and 3) the quantization uncertainty due to the A/D conversion process.

The fixed noise currents indicated are based on actual measurements of the Protoflight Focal Plane assembly. The term "fixed" is used because the noise sources are independent of the signal level. The numbers agree within 20% to noise predictions generated in an analytical model. The noise sources that are included in the fixed noise current are the thermal noise of the feedback resistor ($10^9\,\Omega$ for bands 1-4, $2 \times 10^8\,\Omega$ for bands 5 and 7), the thermal noise of the detector resistance, the shot noise due to detector and FET leakage currents, the input voltage noise of the input FET and the second-stage amplifier, and finally the noise due to the lossy dielectric of the preamplifier input capacitance.

Table 14. Radiance Levels.

Band	Minimum Scene Radiance (mw/cm²sr)	Saturation Scene Radiance (mw/cm²sr)
1	0.28	1.00
2	0.24	2.33
3	0.13	1.35
4	0.19	3.00
5	0.08	0.60
7	0.046	0.43
6	300 K	320 K

The SNR calculations assume that shot noise currents proportional to the square root of the signal currents, rss with the fixed noise currents and the resulting analog SNR is further degraded by the uncertainty of the quantization of the 8-bit A/D converter (which has *conservatively* been assumed to be 7.75 bits). As indicated in Table 13, it is anticipated that the system requirements for radiometric sensitivity will be exceeded in all spectral bands.

Table 15. Modulation Transfer Function

	Ground Target Size (Meters)	IFOV	OTF	Electronics	Syst MTF	Specified MTF
Scan	30	0.64	0.85	0.707	0.38	0.28
Track	30	0.64	0.81	1.00	0.52	
Scan	45	0.83	0.88	0.868	0.63	0.54
Track	45	0.83	0.86	1.00	0.71	
Scan	60	0.90	0.92	0.919	0.76	0.66
Track	60	0.90	0.91	1.00	0.82	
Scan	500	1.00	0.99	0.999	0.99	1.00
Track	500	1.00	0.99	1.00	0.99	

Modulation Transfer Function (MTF)

Table 15 shows the level of performance anticipated for the Protoflight system MTF in both the scan and track directions for the four specified spatial ground target sizes. As can be seen, there are three contributors to the system MTF: 1) the detector instantaneous field of view (IFOV), 2) the optical transfer function (OTF), (diffraction and blur), and 3) the electronic frequency response.

The numbers associated with the IFOV are calculated based on measured detector dimensions (the detectors are the field stops in the system) and the measured telescope effective focal length. (An article has been published describing the measurement techniques used to determine the effective focal length of the TM telescope to an accuracy of 0.01%.)[3]

The electronic frequency response, of the system has been designed to be 3 db down at a frequency of 52 kHz which is equal to $1/2\tau$ where τ is the IFOV dwell time corresponding to 30 meters on the ground. The electronic response is therefore by design (and by measurement at the subsystem level) down by 3 db in the scan direction for ground targets of 30-meter size. In the track direction the electronic response function has a negligible effect since the scanning rate in that direction corresponds to approximately 14Hz.

The performance numbers indicated for the optical transfer function OTF are based on measurements made on the protoflight telescope assembly during EFL testing, and also assume a 5% degradation in performance due to minor surface imperfections in the scan mirror. During the protoflight EFL tests, an astigmatic image was observed which resulted in a 0.009 inch displacement between the best focus in the scan and track directions as shown in Figure 26. The source of the astigmatism was found to be due to a slight mechanical distortion of the primary mirror; a solution to the problem is being pursued. However, the astigmatism can be tolerated by locating the focal plane in the position which will maximize the MTF in the scan direction (where the electronics have an effect) and tolerate the loss of MTF in the track direction. The performance indicated in Table 14 makes this assumption.

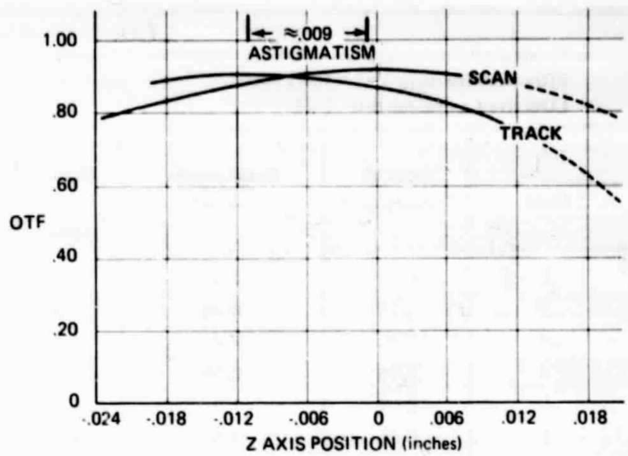

Figure 26. Protoflight EFL Test.

Band-to-Band Registration

The band-to-band registration requirement was tabulated in Table 1 as "< 6 meters." The exact requirement reads as follows: A point imaged in any of the first four spectral bands shall be registered to the same point in any of the other first four bands within 0.2 IFOV alongtrack and crosstrack. This registration error includes the effects of all synchronizing and correcting signals developed by the instrument that are required to process the data into an image. Similarly bands 5 and 7 shall be registered within 0.2 pixel and shall be registered to band 6 within 0.2 of a band 6 IFOV, and band 5 shall be registered to the first four bands within 0.3 IFOV. These requirements shall be satisfied at least 90% of the time and apply to all points along a scan line.

Six meters correspond to 0.2 IFOV which can also be expressed 8.5 μ radians of field angle. Table 16 identifies the various contributors to band-to-band misregistration. The table is divided into bias errors and random errors which affect registration in the scan and track directions within the prime focal plane (bands 1-4), within the cooled focal plane (bands 5 and 7), and between the two focal planes. The performance contributors tabulated have all been verified by subsystem measurements with the exception of the self-induced vibration and thermal contributions which were generated as a result of structural and thermal analyses. The error sources include both static and dynamic effects resulting in dynamic band-to-band registration predictions. As indicated in Table 16 all the band-to-band registration requirements are expected to be met.

Table 16. Band-to-Band Registration Performance, μrad

Error Source	PFP Bands*				Band 5 to Band 7				Band 5 to PFP Bands†			
	Scan		Track		Scan		Track		Scan		Track	
	B	R	B	R	B	R	B	R	B	R	B	R
SM Profile	2.7		0.1	–	0.73	–	0.1	–	4.5	–	0.1	–
Detector Array Alignment Accuracy	0.6	–	0.6	–	4.0	–	4.0	–	4.0	–	4.0	–
Detector Response Nonuniformity	2.0	–	2.0	–	2.0	–	2.0	–	2.0	–	2.0	–
EFL Measurement	1.0	–	1.0	–	1.0	–	1.0	–	1.4	–	1.4	–
Self-Induced Vibration	–	0.88	–	0.84	–	0.37	–	0.37	–	1.76	–	1.39
Thermal	–	–	–	–	–	–	–	–	0.8	–	0.8	–
SLC Profile	–	–	1.4	–	–	–	1.4	–	–	–	1.4	–
MUX Timing Jitter		0.11				0.11	–	–	–	0.11	–	–
RSS Subtotal	3.6	0.89	2.7	0.84	4.8	0.39	4.8	0.37	6.55	1.76	4.77	1.39
Bias + Random	4.5		3.6		5.2		5.2		8.3		6.2	
Requirement	8.5		8.5		8.5		8.5		12.75		12.75	

* Band 1 to Band 4 presented as worse case † Band 5 to Band 1 presented as worse case

Acknowledgements

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2. Thematic Mapper Design Description and Performance Prediction by Jack C. Lansing, Jr., Timothy D. Wise, Edward D. Harvey, presented at The Society of Photo Optical Instrumentation Engineers in Huntsville, Alabama, May 22-24, 1979.
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